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ABSTRACT

The goal of this handbook is to enable those who plan structures for undergraduate science communities to see the process as evolutionary and organic, a process integrally related to ongoing efforts to provide a quality learning experience for the students on the campus. The handbook presents many of the questions that need to be addressed as planning proceeds, and suggests some possible answers to these questions from those with recent experience with facilities projects. The architectural case studies presented throughout include further ideas about how individual institutions have answered questions about purpose and design in ways fitting for their community. Chapters include: (1) "Focusing on Curriculum"; (2) "Focusing on the Campus"; (3) "Leadership and Community"; (4) "The Planners"; (5) "Phases of Planning"; (6) "Technical Issues"; (7) "Spaces That Work"; (8) "The Project Budget"; (9) "Operating Budgets"; and (10) "Fund-Raising." (JRH)

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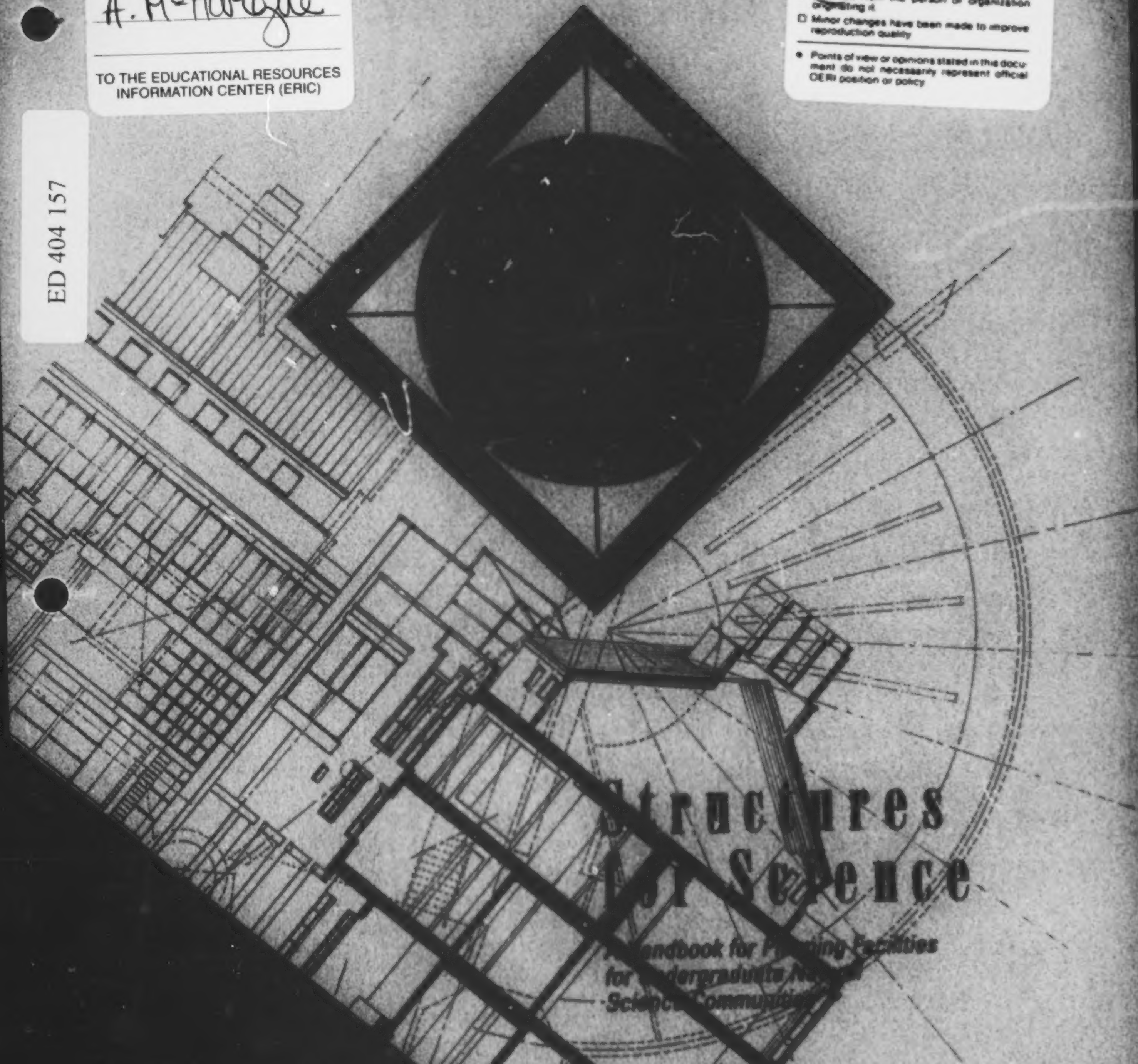

Structures for Science

A Handbook for Planning Facilities for Undergraduate Natural Science Communities

Volume Three

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A special word of gratitude to the many people—faculty, presidents, deans, trustees, facility and development officers, architects, planners and lab designers—who provided text, graphics, and photos—and more important—the ideas and insights, vision and hard work—that made this Handbook possible. To bring this Handbook from vision to reality took the same kind of effort and commitment necessary to plan and realize new spaces for science. ***We recognize you formally "With Thanks" in the final pages.***

ABOUT PROJECT KALEIDOSCOPE

Project Kaleidoscope (PKAL) began in 1989, with support from the National Science Foundation, Directorate for Education and Human Resources (Division of Undergraduate Education), with the charge to outline an agenda for reform of programs in science and mathematics at liberal arts colleges. From the very beginning, those in PKAL leadership roles have focused on *what works*, seeking to distill lessons to be learned from successful programs and reforms developed by individuals and institutions around the country and to bring them to the attention of the larger undergraduate community.

The kaleidoscope serves as the metaphor for PKAL on several levels.

First, it demonstrates our conviction that all pieces of the undergraduate environment—people as well as programs, the physical, financial and administrative infrastructure—must be considered if worthy reforms are to take root and flourish, strengthening natural science communities in the nation's colleges and universities.

Second, it illustrates that persons with diverse experiences, expertise, and responsibilities need to be engaged at appropriate times as reforms are developed, implemented, and evaluated in the undergraduate environment. As different perspectives are shared and connected to the task of reform, meaningful changes will be more productive and enduring.

Third, the kaleidoscope metaphor suggests that individual institutions must look at how programs work in other settings, and put the parts together in a pattern of reform that *works* locally, given their people, program, and infrastructure.

PKAL has presented these messages in Volume I of the PKAL reports: *What Works—Building Natural Science Communities* and in *Volume II–Resources for Reform*. Approximately 500 different institutions, from all sectors of the higher education community have participated in PKAL-sponsored events since 1992. The engagement of institutions beyond PKAL's initial core of liberal arts colleges is significant. Just as reforms at the local level will be more enduring if the broader campus community is involved, so too will the effort to improve undergraduate science, mathematics, engineering, and technology programs nationwide proceed more effectively if the wider community works together.

Our world is one in which science and technology are having a profound impact on almost every aspect of life. PKAL is part of the growing national effort, using the energies and expertise of the undergraduate science, mathematics, engineering, and technology community, to prepare the next generation for that world, for lives that are self-fulfilled, productive, and of service to society.

> **The undergraduate years are critical for strengthening our nation's science and mathematics capacity. It is in college where future scientists and college faculty are recruited and prepared for graduate study; where our nation's elementary and secondary teachers, educators of America's youth, are equipped; and where tomorrow's leaders gain the background with which to make critical decisions in a world permeated by vital issues of science and technology. It is also at the undergraduate level where many able young people—particularly minorities and women—decide to discontinue their study of science and mathematics. The result is a serious loss of talent to the service of the nation, a loss that we cannot afford if we are to remain competitive in a global economy.**
>
> —*PKAL Volume I.*

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ABOUT THIS HANDBOOK

The time of planning structures for science is a unique opportunity for undergraduate institutions. It is our hope that those who use this Handbook come to see the process as evolutionary and organic, one integrally related to ongoing efforts to provide a quality learning experience for the students on their campus.

We suggest that the process is evolutionary because as the project moves forward you will return again and again to fundamental questions about the purpose of the enterprise. You will also be seeking, at every stage, to review issues and gain consensus on questions that need to be asked, on the analysis of responses to those questions, and finally on specific institutional aims and objectives in regard to program and space.

It will help in your planning if you understand the organic nature of the process, seeing how the different activities depend upon one another in what will be a complicated, complex, and extended undertaking. Further, the planning must be inclusive. If the spaces and structures that result from your planning are to provide a safe, engaging, efficient, and cost-effective environment for students and faculty for many years, they must be planned by and for the community that is to use them. Those who understand the nature of observation, investigation, problem-solving, and communication that is at the heart of the scientific way of knowing must have leadership roles in this process. At appropriate stages this planning must also involve those with responsibilities that affect or can be affected by the new spaces: budget officers, campus planners, architects, fund-raisers, faculty colleagues, trustees, deans, and presidents.

In this Handbook we present many of the questions that need to be addressed as your planning proceeds; some possible answers to these questions are suggested in the stories from those with recent experience with facilities projects. In the architectural case studies presented throughout you will find further ideas about how individual institutions have answered questions about purpose and design in ways fitting for their community. These answers and ideas are intended to be illustrative, not prescriptive, reflecting the PKAL perspective that each institution must arrive at answers that make sense for its community—for its students, budget, and mission.

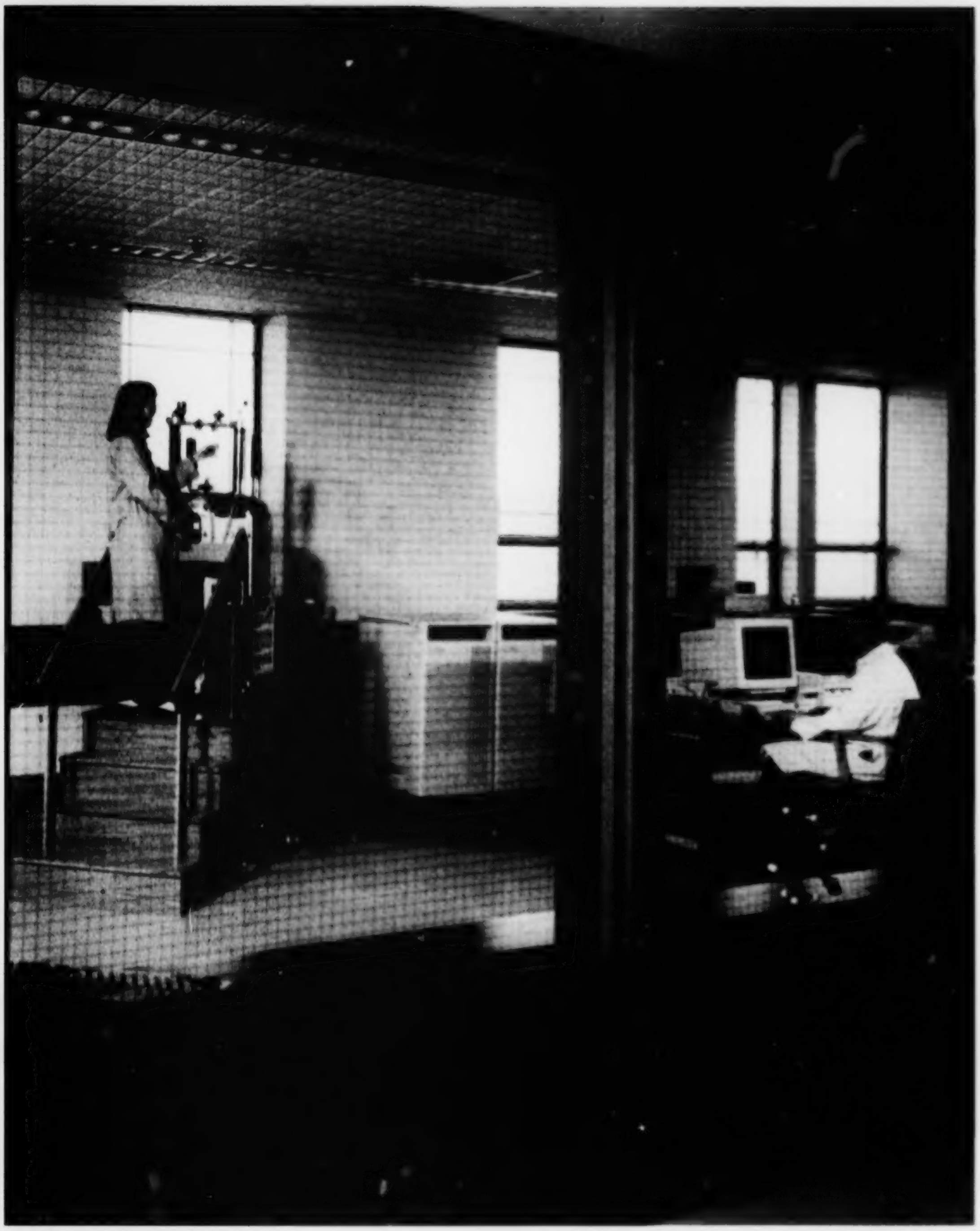
Although the topics are presented in this Handbook sequentially, chapter by chapter, this is not the way that your planning will happen. It will not be a linear process, but will proceed with different (perhaps overlapping) groups considering options for curriculum and campus, for classrooms and for entire facilities, for budgets and fund-raising. But these sometimes parallel, sometimes converging, activities are all part of the adventure of planning, and it is our hope that with this Handbook we have provided you with both the nuts and bolts and the inspiration to move ahead confidently.

—Jeanne L. Narum, Editor

Whatever its medium, a work of art has an organic character. It is not internally undifferentiated and homogeneous, but is complex in quality and structure. Yet if it is to be considered a work of art at all, it must possess some measure of inner unity and coherence. Its parts must be artistically related to one another so as to contribute to the artistic vitality of the composition. The term "organic" is of course taken from biology and applied to art metaphorically. A biological organism is a living entity composed of parts which, while contributing to the life of the whole, also depend upon one another and upon the whole organism for their own being. Thus a tree is a living organism because its life depends upon the healthy activity of its branches, leaves, and roots, and because these, in turn, depend upon the tree as a whole, and thus upon one another, for their own vitality and growth. A work of art is obviously not a living organism in the strict biological sense....

But as a work of art, it has an artistic vitality of its own. Its parts derive their artistic significance from the larger whole of which they are the constituent members, and its artistic unity, in turn, depends upon the contributions of its several parts and aspects.

—T.M. Greene, The Arts and the Art of Criticism.



PART ONE

FOUNDATIONS FOR PLANNING

Chapter I
Focusing on Curriculum

Chapter II
Focusing on the Campus

Chapter III
Leadership and Community

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PART ONE

An appreciation of what is happening in science today, and of how great a distance lies ahead for exploring, ought to be one of the rewards of a liberal arts education. It ought to be a good in itself, not something to be acquired on the way to a professional career but part of the cast of thought needed for getting into the kind of century that is now just down the road. Part of the intellectual equipment of an educated person, however his or her time is to be spent, ought to be a feel for the queernesses of nature, the inexplicable things.

And maybe, just maybe a new set of courses dealing systematically with ignorance in science might take hold. The scientists might discover in it a new and subversive technique for catching the attention of students driven by curiosity, delighted and surprised to learn that science is exactly as [Vannevar] Bush described it: an "endless frontier." The humanists, for their part, might take considerable satisfaction watching their scientific colleagues confess openly to not knowing everything about everything. And the poets, on whose shoulders the future rests, might, late nights, thinking things over, begin to see some meanings that elude the rest of us. It is worth a try.

—*Lewis Thomas, Late Night Thoughts on Listening to Mahler's Ninth Symphony*

We begin by focusing on the relationship between mission and planning for curriculum and campus. We also suggest ways that campus leaders can foster an environment in which the community comes to a common understanding about identity and mission, aims and objectives, and about the means to achieve those ends.

There are several paramount concerns as you begin, including the background and aspirations of your students, and the interests and strengths of your faculty, as individuals and as members of the community. You must also give attention to how and why students come to understand what scientists do, to your vision of an environment for teaching and learning in which students come to understand how scientists comprehend the world. Whether you are considering renovating a single classroom or constructing a new multidepartment facility, this is a critical time to step back and ask: "*How can we improve the environment for learning? How do we know what works?*"

In PKAL, we propose that what works is a natural science community, one in which all students—majors and nonmajors alike—are actively and personally engaged in learning, have persistent opportunity to do science as scientists do science, collaborate with student and faculty colleagues. Such natural science communities require facilities different from those built twenty or thirty years ago, when there were fewer opportunities for students to enter into apprenticeships with faculty, when the tools for learning were less sophisticated, when pedagogical approaches were based on a different understanding of how students learn, and—most important—when the program was designed primarily for majors—those who were to become the next generation of scientists.

As you begin, be especially attentive to the rich possibilities inherent in the planning process for creating and sustaining community on your campus, community within and beyond the disciplines to be housed in the new spaces. Your goal should be a structure with soul, one which expresses the institution's values, one which announces your commitment to fostering productive relationships. The spaces should enrich the work and the lives of the students and faculty who today do science within its walls, provide a safe and hospitable environment for learning for years to come, and contribute to the coherence and humanity of your campus. This will happen if you ask some basic questions about the purpose of the enterprise as you begin, and return to those same questions at appropriate times throughout your planning.

CHAPTER I: FOCUSING ON CURRICULUM

> *B*ut an institution cannot be built of wholesome usage, until its precise mission has been determined. An institution is a machine in that its whole structure and functioning must be divined in view of the service it is expected to perform. In other words, the root of university reform is a complete formulation of its purpose. Any alteration, or touching up, or adjustment about this house of ours, unless it starts by reviewing the problem of its mission—clearly, decisively, truthfully—will be love's labors lost.
>
> —*José Ortega y Gasset. Mission of the University.*

Introduction.

You are convinced that your undergraduate students and faculty need new spaces for teaching, learning, and research in the sciences and mathematics. For some, the tendency at this point is to reach for a piece of paper and to begin sketching out labs, classrooms, and offices. That is *not* the place to begin.

Instead, your first order of business should be to wrestle with issues of mission, with issues relating to aims and objectives of the academic program, and with issues about the shape of the curriculum to be housed in classrooms and labs. Such wrestling with critical issues must be done before you can know what kind of facilities are needed.

This *PKAL Handbook on Structures for Science* thus begins by connecting facilities planning to larger institutional issues, mindful of Ortega's exhortation that sound and healthy institutions are those that have put the "question squarely, '*What is a university for, and what must it consequently be?*'"

Institutional Mission.

Discussions about institutional mission take place with regularity on a campus—at the time of accreditation, at the beginning of a new presidency, or at the start of a capital campaign; they provide direction at critical times in the life of a college or university.

The planning of a major renovation or new structure for science is such a critical time, and this is why we encourage you to start your planning here. Such discussions help avoid *ad hoc* decisions; they shape and reinforce an institutional commitment to new and renewed spaces for science and mathematics.

Why is it essential to generate such a commitment?

◆

What is a university for, and what must it consequently be?

◆

Undergraduate science facilities are expensive—to build, to maintain, to update, and to replace. For the number of students involved, the costs may appear disproportionate, particularly to faculty in other departments with higher enrollments.

There must be a campus-wide understanding about how building and sustaining strong programs in science and mathematics connect to the institutional mission of preparing students for the world in which they will live and work upon graduation. As science and technology have an increasing impact on all of life, colleges and universities have a responsibility to make a rigorous encounter with science and mathematics an integral part of the undergraduate curriculum.

WHAT WORKS: CONSIDERING MISSION

The Drury College Story

In 1987 we decided to reconsider the mission statement at Drury College, which had last been reviewed decades ago, a number of college presidencies ago. Our new president and senior administrators wanted to recast the mission statement in a way that would give a vitality, an engaging purpose, a focus, and a new cohesion to the Drury education in which they so strongly believed.

The age of the mission statement was not the only reason for this reconsideration. Institutional leaders saw the approaching 21st century as a significant reason for reexamining the stated institutional mission. Given that a new science facility was anticipated, a critical issue as we undertook the reformulation of our mission statement was how the role of science in society had changed since the last mission statement was shaped. We spent much time talking about the need for a higher level of science literacy in the general populace, given science's increasing impact on all aspects of our lives. We recognized that liberal arts graduates will need to "sort scientific sense from scientific non-sense" in the workplace and in their role as citizen.

The recast mission statement that emerged from our discussions provided a distinctive purpose and direction for the planning of curriculum and space that was to follow: *"[to prepare] students for a time of significant global adjustment by strengthening their understanding of science and technology, their perception of the interrelatedness of all things, their appreciation for beauty in nature and the built world, their love of truth and freedom."*

The faculty and administrators resolved that a new Drury curriculum would translate that mission into action; this included a commitment that Drury students would graduate familiar with the methods, capabilities, and limitations of science, mathematics, and technology.

The reformulation of the mission statement was not carried out by administrative fiat. The whole faculty of the college, not just the science faculty, participated in the discussions, agreeing that science should be a greater focus of our students' studies. Faculty voted that the new curriculum would require all students to complete six credit hours of "Science and Inquiry," three credit hours of "Mathematics and Inquiry," and three credit hours of an "Undergraduate Research" course.

Why would the general faculty of a liberal arts college decide to require so much hands-on science instead of more of the great books? The primary reasons were our understanding of science as one of the greatest achievements of the Western tradition, and that the scientific and technological enterprise is shaping the future in which our students will live and work. We also recognized that many disciplines beyond the natural sciences—political science, sociology, economics, psychology in particular—depend on statistical and mathematical analysis. Proofs coupled with calculations are now a fixture in the work of the social sciences and help justify the courses in mathematical and scientific inquiry. Finally, collectively we were convinced that students needed to achieve an appreciation of the method, the process, and the intellectual tools of science, thus the required undergraduate research course.

There were unexpected consequences, all positive, from the process of rethinking Drury's mission. No one had anticipated that a new feeling of invigoration would come to all levels of the campus, or that a new sense of purpose would emerge. This momentum was particularly salutary as the college moved from consideration of mission and curriculum to thinking about the new science building. Because as a faculty we had a clear sense of direction for the academic program, we think we have an opportunity to achieve the perfect science building for our community. Without the self-evaluation in the process of considering the mission statement, we might have made the mistake of blindly selecting "any old science building's" design when we decided to update our facility. We all agree that the college was lucky that planning a science facility was not something that could happen overnight. It takes time processing the plans—thinking about them—and it takes time talking about them and connecting them to some larger institutional priorities. We are better off for having taken the time. Our design plan is better because it has a coherent idea behind it; our building will be better and it will be our own because of it.

In the process of planning, the words of Winston Churchill caught the attention of a vice president: "We shape our buildings; thereafter they shape us." Now that quotation is at the top of all documents we prepare in the course of designing the new science facility.

By beginning with a consideration of mission and academic plan, your faculty and administrators, trustees and staff will determine how renewing programs and spaces (which go hand in hand) fits into your mission and shapes your planning. As these discussions proceed, priorities for the short- and long-term will emerge for your curriculum, your campus, and your fund-raising efforts, and strategies to achieve those priorities will be identified. These discussions will not be easy, especially in an environment of stiff internal competition for limited resources, but they are an essential foundation for successful facilities planning.

In the context of discussing the institutional mission, there will come an understanding that, although the financial cost of these structures is significant, failure to act will also have great consequence. It may be difficult to assess the psychological impact on students and faculty of outmoded, unsafe, and cramped facilities. It is not difficult to assess how programs that are potentially exciting and productive are hampered by constraints of spaces and technical capacity, and recruitment and retention of strong students and faculty are constrained by spaces that are found wanting.

Depending on the scope of the anticipated project, the time between first thoughts and physical reality may be lengthy, but this is a time for deep thought about the meaning of education on your campus, for all members of the community to ask,

"How can new and more appropriate spaces contribute to better learning in science and mathematics for our students?"

When institutions move too quickly from the perception of problems with spaces to the selection of design professionals, the resulting renovations or new construction will limit, rather than nurture, the natural science community that is desired. It is not acceptable simply to think about how many square feet for laboratories, about safety and siting, or about configuration of furniture. This is a time to think about the process of education on your campus and how present and proposed programs reflect *your* particular institutional mission and identity.

Questions that might be asked at this stage include:

- When was the last time we revised or reaffirmed our mission?
- What are our institutional priorities? How have they been determined?
- Do we have a current academic plan? How does it connect to our mission? Is it compatible with our understanding of the future in which our students will live and work?
- Do the changes we envision for the sciences fit within our mission and plan, in terms of numbers of faculty and students, in terms of building and sustaining strong programs?
- Does our thinking about the sciences represent several independent visions or a coordinated, institution-wide vision?

This reaffirmation of mission and reexamination of academic plan should take place at the departmental as well as at the institutional level. It is the essential beginning point, the first step in bringing the right people together to explore new spaces and structures for science. As your planning proceeds over the coming months and years, if it is rooted firmly in a common understanding of the institutional past, present, and future, if you have taken the time to reexamine and explore the underpinnings and rationale for your academic program, the resulting spaces and structures will serve you well.

This is a time, also, to broaden the conversations and engage in dialogue with colleagues on other campuses, to learn about new modes of teaching and learning and how they have been implemented in different settings. This is a time to learn about *what works.*

WHAT WORKS

Project Kaleidoscope asserts that the most important attribute of undergraduate programs that attract and sustain student interest in science and mathematics is a thriving "natural science" community of students and faculty.

Such natural science communities offer students a learning environment that is demonstrably effective, where:

◆ *Learning is experiential, hands-on, and steeped in investigation from the very first courses for all students through capstone courses for science and mathematics majors.*

◆ *Learning is personally meaningful to students and faculty, makes connections to other fields of inquiry, is embedded in the context of its own history and rationale, and suggests practical applications related to the experience of students.*

◆ *Learning takes place in a community where faculty are committed equally to undergraduate teaching and to their own intellectual vitality, where faculty see students as partners in learning, where students collaborate with one another and gain confidence that they can succeed, and where institutions support such communities of learners.*

Programs organized around these guiding principles motivate students and give them the skills and confidence to succeed. Thus empowered, students learn science and mathematics.

—Project Kaleidoscope, Volume I

The stories on *what works* in this chapter and throughout the Handbook illustrate how faculty on campuses across the country have come to understand how to build better environments for learning. They tell of faculty who have analyzed advances in the disciplines and in technology and who recognize how those advances call for a reexamination of the present culture of teaching and learning in the sciences and mathematics. These stories tell how faculty have made choices about what is to be taught and what does not need to be taught—choices required by the ever-expanding body of knowledge and the increasing sophistication of technologies available for use at the undergraduate level. These stories witness to the power of the process of arriving at an institutional commitment about mission, priorities, and strategies. Most important, these stories reveal how learning is enriched when students take responsibility for constructing their own knowledge.

WHAT WORKS: HANDS-ON LABORATORIES

The Dickinson College Story

The idea that learners should be active constructors of their own knowledge is a theme that runs through many of the current successful reform efforts in undergraduate science. Our goal as we began the Workshop Physics program at Dickinson was to help undergraduates move from being passive receivers of truths revealed in the canonical introductory science texts, to being disciplined solvers of problems, and finally to becoming constructors of their own knowledge. Our goal was to help our students ask and answer the questions posed by Arnold Arons, "*How do we know? What is the evidence for...?*"

A couple of observations or assumptions guided us as we developed Workshop Physics. We assumed that the acquisition of transferable skills of scientific inquiry is more important than either problem solving or descriptive knowledge about physics. There were two reasons for this. First, the majority of students enrolled at both the high school and college level do not have sufficient concrete experience with everyday phenomena to think scientifically or mathematically about them. The processes of observing phenomena, analyzing data, and developing verbal and mathematical models to explain observations gives students an opportunity to relate concrete experience to scientific explanation. Second, when anyone begins the task of acquiring a large body of knowledge such as physics, the best strategy is to learn a few things thoroughly and then learn about investigative processes. Thus, we decided to reduce content and emphasize the process of scientific inquiry.

In reducing content, however, we wanted to retain topics that involved directly observable phenomena as well as mathematical and reasoning skills that are applicable to other areas of inquiry.

After thinking about *what* is taught and the general goals we wanted to meet, we focused on specific ways we would change the *way* physics is taught. While we agreed that listening to traditional physics lectures is a viable alternative to reading physics textbooks, we also knew that lectures are not the best vehicles for helping students learn how to think or conduct scientific inquiry. Furthermore, many educators believe that a student's peers are often more helpful than instructors in facilitating original thinking about problems and that the time spent by students passively listening to lectures is better spent in direct inquiry and discussions with their peers. As we began to see the roles of the instructors as those of helping create the learning environment, leading discussions, and engaging students in Socratic dialogue, we made another decision: we would eliminate formal lectures.

We decided to change how physics is taught in another way, by integrating computer tools such as spreadsheets, interfacing, and video analysis into classroom and lab work. It was clear to us that computers, when used as flexible tools in the hands of students for collecting, analyzing, and graphing data, accelerate the rate at which students can acquire data from real experience and develop abstract theories compatible with their data. However, computer-enhanced inquiry does take time and students cannot "cover" the amount of material normally introduced in an introductory physics course.

Our plan for implementing Workshop Physics ran into some physical impediments when we tried to put it into practice in our existing spaces:

◆ labs had long tables in a linear "lunch counter" arrangement. With everyone facing forward, students could only engage in dialogue with immediate neighbors; the primary location of the instructor at the front and center of the room inhibited class discussions.

◆ instructors and student assistants could not see computer screens to see if students needed assistance. They had to squeeze between the rows to assist students.

◆ the computers blocked students' views of demonstrations.

◆ no space was available to use a video camera to capture digital video images of motion experiments for computer analysis.

Although we are limited by the immovable walls of our 110-year-old building, we figured out that it was possible to solve our major

I'd like my students to learn how to learn, to be involved in the process of teaching themselves. And to make commitments—not to be in love with the position, but to be in love with the search, so that if they find themselves not able to hold a position, if it turns out to be untenable, then they should have enough courage to say, "You know what I said last week? I no longer believe that."

—Maya Angelou, 1993.

problems with minor renovations. These included removing all unnecessary equipment; installing new furniture, new computers, and a central raceway track for human scale experiments; and rewiring the room for a faster "ethernet" computer network. We now have:

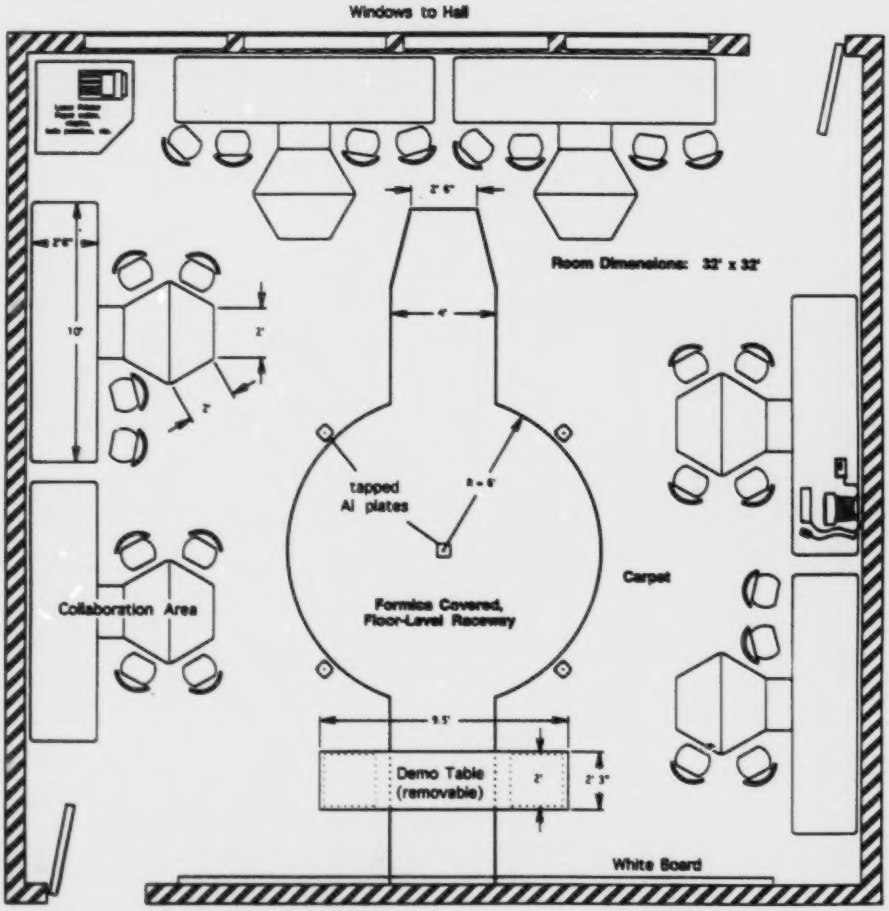
◆ specially designed "T" shaped workstations for student groups of four. The top of the "T" consists of a long table with a computer on each end so students can work in pairs for data analysis and computer modeling. The stem part of the "T" ends in a hexagonal table for roundtable discussions. This has increased the number of group discussions.

◆ workstations that are arranged in a U-shaped configuration around the perimeter of the room. Instructors and student assistants can see at a glance what each group is doing.

◆ a smooth, level Formica-topped raceway installed in the center of the room. It consists of a 28-foot long linear segment with a 6-foot diameter circular area in the middle. The center and perimeter of the raceway are outfitted with electrical outlets and tapped metal plates to allow flexible structures to be built in the center of the room using rods and clamps. A ceiling support capable of holding 400 pounds was installed above the center of the raceway. A video camera is mounted on the ceiling to tape motion on the raceway from above.

◆ a special demonstration table with a removable top to free up space when it is not in use. It is flat, thus unencumbered for demonstrations, and it has a sink and gas and air outlets hidden underneath the removable top.

After two years of experience with the new classroom, we are finding that having each group of four students sitting in a circular array rather than at a lunch counter has enhanced the level of student collaboration. We are doing many new and exciting demonstrations using the central raceway, and the digital video moviemaking activities have enabled students to perform exciting and educational experiments with two-dimensional motions. Given the constraints of our 110-year-old building, we at Dickinson College are very happy with our new space.



Dickinson College
Workshop Physics Program

Room:	Tome 104
No. of Students:	24
Design By:	Priscilla Laws Hans Pfister
Date:	1-July-1992

WHAT WORKS: COMPUTERS AND COMMUNITY

The Carleton College Story

About ten years ago, Carleton College's Mathematics and Computer Sciences Departments were cramped inside 106-year-old Goodsell Observatory. Faculty in the departments had particularly limited space—offices were in an incoherent array of hovels carved from old storage areas, darkrooms, and even broom closets. One faculty member suggested Goodsell "should be listed on the national register of prehistoric buildings," even though it really felt like you were walking into the nineteenth century when you crossed its threshold. The fixed-in-stone construction and the age of the building made it impossible for us to integrate new and better computer equipment into classes and workrooms. We began to think the building was dangerous too, because the classroom in which computers were housed was crammed—wires and conduit for the computers were exposed and unprotected everywhere—and we could do nothing, because the walls were made of solid stone. Furthermore, lack of space in Goodsell meant that our programs were scattered around campus. The campus drop-in math tutoring center, staffed by math majors, was in the academic building farthest away from Goodsell. A statistics laboratory was in a shack that had been slated for demolition at the end of the Korean War almost 45 years ago.

We had three primary goals as we set about planning a new facility. First, we recognized that in the old spaces, the department missed a sense of community and that this had a deleterious effect on our teaching and learning. The scattering of departmental spaces across the campus diffused our productiveness. Students could not use faculty office hours if, for example, they were on the other side of the campus in the math center when they needed help. There was no place to hang out and no easy way to generate and sustain a dialogue between faculty and students. Majors came to the observatory only for a specific purpose, to get a signature from their teacher or advisor, for example. Our first goal, therefore, was to provide spaces that foster a sense a community.

Second, we recognized that the discipline of mathematical sciences had undergone significant expansion and change within the last 15 years or so, and that we were now being called upon to adapt courses for majors in previously unconnected disciplines such as economics, sociology, political science, history, and psychology. These students brought different expectations, not to mention fears and different learning styles, to our classes. To spark the interest of these students and to make them enjoy the overlap of their majors with mathematics and computer science, the department needed to rethink teaching and learning in general terms. Thus, our second goal was that the spaces accommodate a variety of pedagogical approaches, as well as students with different learning styles and career aspirations.

Finally, our third and most important goal: integrating computers into the classroom. In a sense, this may have been the most common, or sensible of our goals: to bring our program up to date. No one in education needs to be reminded how computers have taken over the landscape of academic institutions, and it is easy to explain our need for renovation by stating, "We need to update our computers for the 21st century." Carleton had made a commitment to computer science by adding a major in it as recently as 1986, and *integrating technology* into this new major and in mathematics became our special task.

The advance in software technology has been tremendous. As the abacus is to the pocket calculator, so the pocket calculator is to today's mathematics software. In Goodsell, the department's problem was that working computers into a class presentation always required a great deal of advanced planning and set-up time.

In the new building, we wanted to be sure there was a computer infrastructure so reliable and accessible that computer improvisation would be possible. We made plans for making computer demonstrations as easy for a professor as chalk and blackboard would be. We did not want professors to say, in the course of teaching, "If we had a computer, it could show you exactly what I mean."

Integrating computers would also help us meet our second goal, that of making math interesting to students from other disciplines. We knew that the pocket calculator won its battle of the math classroom: more students at all levels use it to compute answers instead of needing to do every computation on paper. If the computer could be used by students of other disciplines in the same way, to do the real pencil-lead-crushing labor of computations, then the department could arrange the problems they set out in more interesting ways and could use class time and assignments to show the fascinating qualities of math and computer science.

In the new Center for Mathematics and Computing at Carleton, we achieved our three goals. The new drop-in math help room is at the core of the building, open to view of all who enter; it is on two floors, permitting easy access to faculty offices. Students can now run down the hall to get a quick answer; professors walking by the glass-walled drop-in center can stop and ask how things are going. We have a faculty-student lounge and conference room, where coffee, conversation, and journals can be shared. This room has a beautiful view of the campus lakes; it is a comfortable space—one which creates a "we are in this together" environment. This was an essential community space in our planning; it was never seen as a luxury that could be deleted as budgets were cut.

Several other community-building features were also included, some at very little cost. In the springtime, humanities classes often would move outside, while math departments were inside, tied to their blackboards. On the new building, one outside wall is black slate, with a small amphitheater landscaped at its base. Inside the building, display areas were created for student posters. We now have a poster component to a final paper, and students work hard designing the poster because they know it will be displayed in a public space.

All other advantages aside, computers are now fully integrated into all our classroom teaching and have met our highest hopes. A computer projection screen with advanced mathematics software is running during an entire class period. A professor can as easily demonstrate or answer a question by computer demonstration as by using chalk and blackboard. The dynamism of computer demonstrations are an enhancement of, not a replacement for, blackboard use. They easily integrate the best of technology into the spontaneity of engaging teaching.

Beyond putting computers into the classrooms, we made four separate computer "laboratories," recognizing that it is not enough to have one computer center in the building or on campus, and workrooms with computers scattered all over campus. The separate labs each emphasize a different part of mathematics or computer science: a statistics lab, a "Mathematica" software lab, a lower-level and an upper-level computer lab. The new proximity of labs to classrooms makes it easy to integrate lectures and lab work.

Here is what made our project so valuable to the college: a computer infrastructure that is the core of the building, unifying formerly outstretched parts of the department, making the department closer to other disciplines on the campus by making the subject matter more open and teaching presentations more dynamic. We also have the latest in technology. We have everything we wanted.

Carleton College Center for Mathematics and Computing

Northfield, Minnesota

Architect: Cambridge Seven Associates
Cambridge, MA

Associate Architect:
SMSQ Architects
Northfield, MN

Project Type: New Construction

Size: 42,000 GSF
25,000 NSF

Building Occupants:

- Department of Mathematics and Computer Science
- Academic Computing and Networking Services
- Administrative Computing

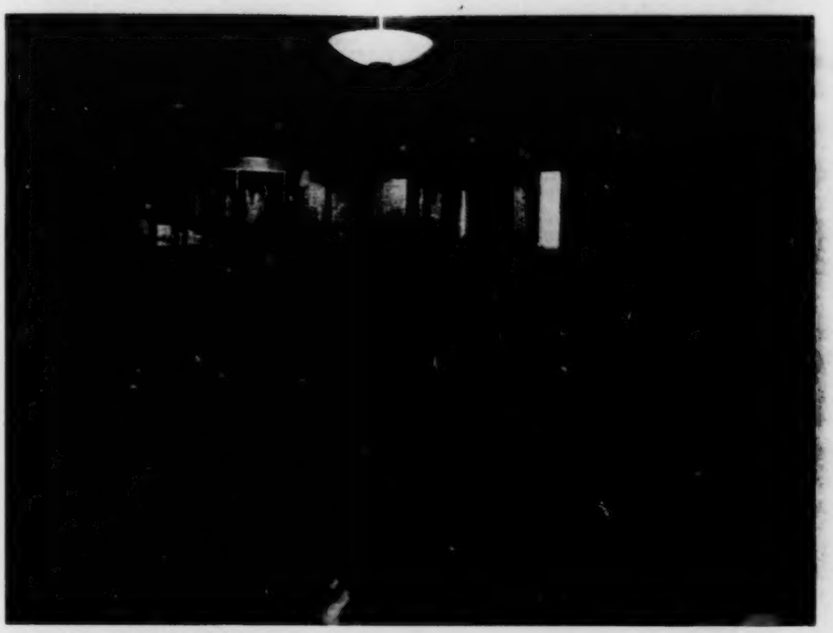
Construction Cost: $4,600,000

Project Cost: $6,500,000

Completion Date: September 1993

Background

The architectural program for the Center for Mathematics and Computing (CMC) grew out of a mission statement that was developed by the three tenants which called for the creation of a new identity as well as an enhanced sense of community. Central to this mission was the design of a facility with a "heart" which would promote student, staff, and faculty interaction with easy access to resources. The belief was that a cohesive academic department and interaction with academic support services would promote more effective teaching and enthusiastic research.



Main entrance/lobby area.

Building Design

The resulting design is a 4-story, 'L'-shaped building utilizing a steel structure with a brick and limestone veneer. The center piece of the building lobby is a floor tile design invented by Roger Penrose, British mathematician and physicist. It is an elegant aperiodic design which illustrates the nonrepeating, Golden Ratio in nature.

The building project also included the extension of the campus utility tunnel, new vehicle and pedestrian access routes, considerable site improvements, and a lower level connection to the adjacent Boliou Art Hall.

Classroom and Laboratory Wing

The classroom/laboratory wing includes six computer classrooms, three general classrooms, a computer library/resource room, one specialized computer classroom with a tiered seating arrangement, and a Technology Resource Center and a Student Computing Resource Center both administered by Academic Computing. This wing has an extensive overhead and underfloor raceway system to allow for flexibility within the telephone/data network. Each classroom and laboratory has a separate air-conditioning unit to accommodate the higher occupancy, longer hours, and increased equipment loads.

Office Wing

The office wing includes 36 administrative and academic offices, the campus administrative printing and computing facility, a demonstration area for new equipment, and three small seminar rooms. This wing is zoned separately and incorporates a straightforward mechanical system to take advantage of the shorter hours of use and a simpler overhead raceway system because of lower data handling needs.

Math Skills Area

At the intersection of these two wings is the main entrance/lobby area and the dramatic two-story Math Skills area. The Math Skills area is adjacent to the two floors of offices and creates the focal point of the building where faculty, students, and staff come together in a relaxed learning and teaching environment. This area, which encompasses interior circulation, a library, tutorial areas and study space, provides maximum natural daylight through a variety of windows and skylights.

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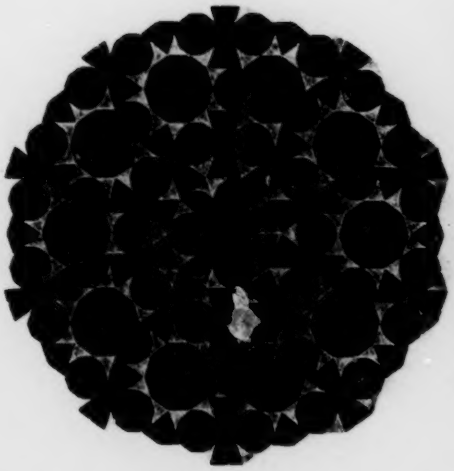
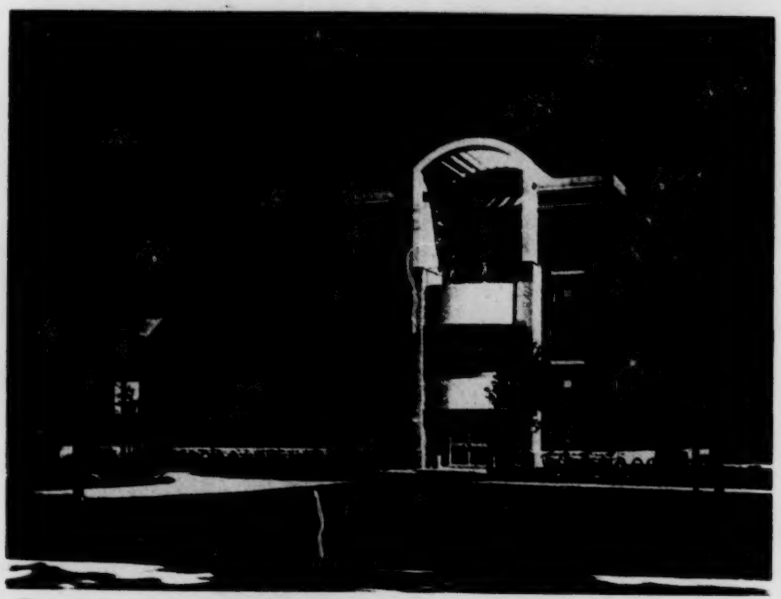
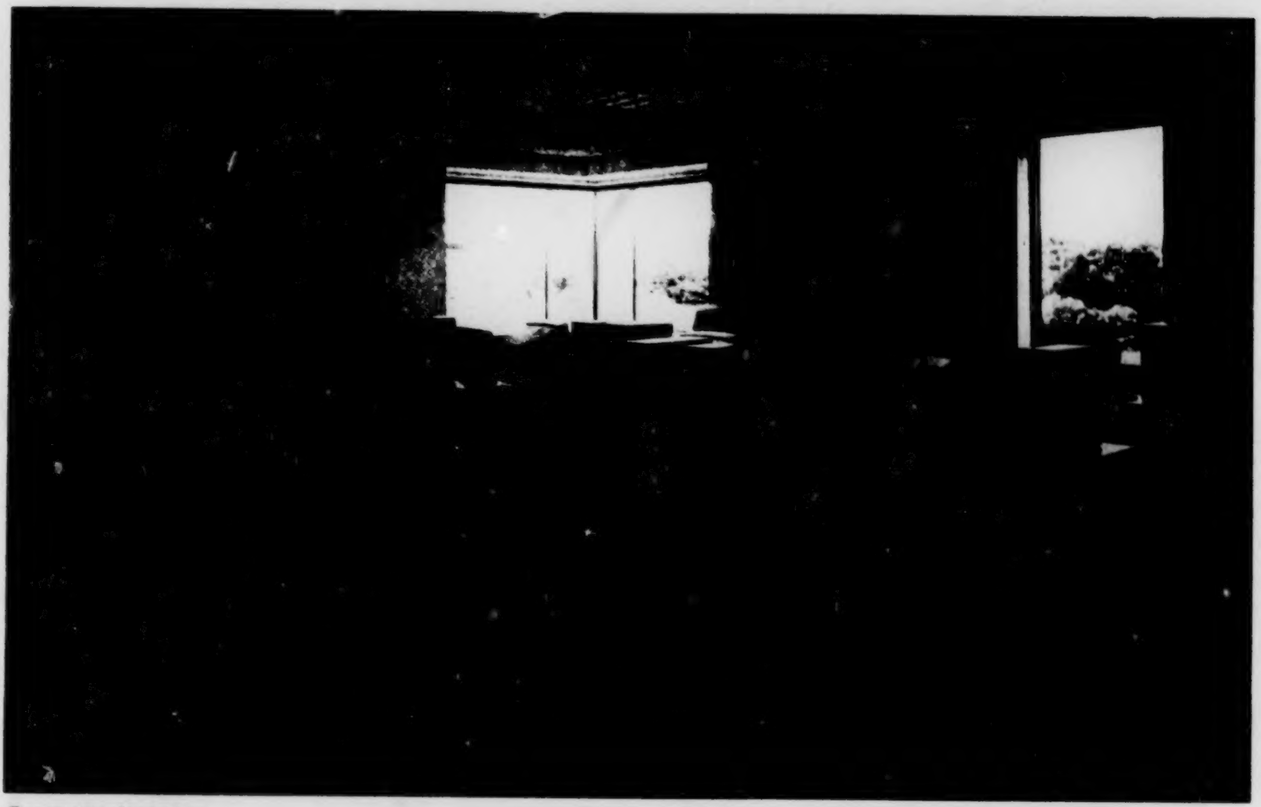


Penrose floor tile design.



Two-story math skills area/external view.



Computer classroom.

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WHAT WORKS: RESEARCH-RICH SPACES

The Grinnell College Story

For nearly fifty years, science faculty at Grinnell have been collaborating with students as partners in research; during that time we have developed a tradition for blurring the distinction between teaching and research in a way that makes sense for our students, faculty, and college.

The tradition got its start in 1947 when, after a distinguished career in industry, Joe Danforth, joined the chemistry faculty and invited students into his research lab. This single action had an immediate impact beyond that one lab. Other faculty, then and in the years to follow, took note of Joe's example and incorporated such collaborative efforts in their own work. By the mid-1970's, the entire chemistry department and many faculty in the departments of biology and physics had embraced this model. By the early 1990's, when we began planning for new spaces for our science programs, nearly all science faculty were actively engaged in research with students during the academic year as well as during the summer.

Such a research-rich environment was relatively easy to develop, even given the severe limitations of our building. What we had going for us were faculty members who understood that the interactive combination of teaching and scholarship that is most satisfying to a teacher-scholar results in the most instructive and engaging education for students. New faculty coming to Grinnell were clear about this vision, and, indeed, were appointed on the basis of having a research agenda that could appropriately involve undergraduate students. Faculty development activities (supported by internal and external grants) focused on the goal of keeping all faculty excited about scholarship, up to date in their fields, and prepared to connect research and teaching in a way that makes sense for their students. There has been persisting administrative support, including the appointment of top-notch grant officers, to develop a faculty who, individually and collectively, serve as role models for students and provide intellectual stimulation for colleagues.

Having students as collaborators has benefitted both our students and faculty in many ways. We know students play a significant role in the natural science community on the Grinnell campus. This is so because learning is not a one-way street for us. As faculty, we learn new ways of looking at old problems as we see how students approach research we may have been wrestling with for years. They bring new insights to the questioning, and we gain a fresh perspective on our work and proceed more productively.

Our experience over the past decades has shown how an undergraduate research experience can transform a student. In blurring the distinction between teaching and research, we are giving students opportunity to really learn what science is about, including such mundane endeavors as figuring out what type and size flask to use for a chemical reaction, how to use or fix an instrument, and how to find what they need to know from the library or through the computer network. Our students really understand what a scientific community can be.

This experience has also taught us several lessons about developing a research-rich environment that have been instructive in planning new facilities: lessons about space, about program, and about the connection between space and program.

For more years than we would like to remember, we had been making makeshift, piecemeal changes to a facility that was built in the early 1950's, when neither *undergraduate research* nor *natural science communities* were part of the vernacular at institutions like Grinnell. Although some of the original signs on labs here and there around the building indicated that they were then being used for student/faculty research, they were not intended for, and did not accommodate well, faculty-student collaborations. Neither did the original building serve as a setting for the kind of community that we were aiming toward.

When the building was first expanded in 1965, some *student-spaces* were included to encourage community, such as carrels and seminar rooms, small rooms for specialized calculators (they were still big then), and a small science library. But even though some spaces were designated for student/faculty research, they were not well designed; they were too small and lacked in the sense of community we were seeking. It was not until the chemistry department converted an old introductory chemistry lab to a large student research lab, by providing students space and opportunity to do truly experimental work, and not have to pack up an experiment at the end of an arbitrary time period, that we began to have the kind of space that showed us what could be possible.

By the 1970's, at almost all hours of the day or night, you could find students working in a lab; science majors (upon request) were issued keys to the building, and the official closing time for the building became 1 A.M. Security was never a problem, perhaps because in some sense another distinction was being blurred: the students now were feeling like the building *owners*. They were turning the science building into the campus center.

The lesson that students needed to have ownership of the building was one we did not forget as we had begun thinking about new facilities: whatever we did, we intended to provide an engaging space, one that the students still felt they owned, one that provided a hospitable setting for the sometimes noisy, always messy activity that is the doing of science. Further, we wanted to make certain that our faculty had spaces that worked for them; we wanted to keep attracting strong faculty, and encouraging them to be as creative and productive as possible. And, given our difficulties with our old spaces, we wanted to provide research spaces that would serve our faculty today—and yet be flexible enough to be able to accommodate changes in the direction or research or in the disciplines in the years ahead.

Another lesson that we learned from experience was that a research-rich environment needed to be precisely that, a total environment for all students, not just for senior majors: another distinction blurred! We had begun to realize that for all students, (not just senior majors) learning about research needed to begin early. Thus, over the years we had begun to introduce projects that involved investigation throughout the curriculum. We introduced students, even in introductory courses, to more modern techniques and instrumentation, challenging them to trust their own observations, gain facility with identifying and finding information, often using computers, to discover ideas on their own. In doing this, what we taught changed also, moving from tired, bookish and abstract material to concepts basic to the discipline. These changes, initiated to serve majors, served as the best introduction to science for future musicians and policy makers as well.

In the process of our planning, we learned many more lessons about what was important to us in the program and space, but what drove us was a vision of a research-rich environment, for students, majors and nonmajors, first-year students and senior majors, and for our faculty, an environment that was welcoming and hospitable. We learned how to keep the tradition of blurring distinctions:

◆ between teaching and research. In the new building, neither instruments nor spaces would be definitively classified as instructional or research, but could serve both purposes easily.

◆ between learning science and doing science. We aimed at lab spaces that resemble those used for research in the real world, insofar as possible. Instrumentation, equipment, computers, and places for students to work would be similar to those used by research scientists.

All in all, it is our dream that the Bowen Hall of Science, with its new spaces, will continue the tradition of being the most lively building on campus.

Grinnell College
Bowen Hall of Science

Grinnell, Iowa

Architect: Holabird & Root
Chicago, IL

Lab Design: Research Facilities Design
San Diego, CA

Size:

Net Square Feet	
Laboratories	46,500
Offices	6,800
Student Services	6,200
Classrooms	7,500
Total Net Square Feet	67,000
Total Gross Square Feet	115,500

Construction Cost: $12,200,000

Completion Date: (Phase I) June 1997

The Bowen Hall of Science at Grinnell College houses the Departments of Biology, Chemistry, Mathematics and Computer Science, Physics, and Psychology, and the Science Library. The first two wings, constructed in 1952, are comprised of a three-story structure (including a basement) and a single-story wood-frame structure. In 1965 a three-story addition was completed, and in 1986 an addition was built which houses the Mathematics and Computer Science and Psychology Departments. The 1952 and 1965 wings of the building no longer serve the educational program very well. They were constructed when there was little student-faculty research, fewer scientific instruments, no computers, and the standard mode of instruction consisted of large traditional lectures. Furthermore, the mechanical systems, although well maintained, are beyond their useful lives and do not provide the needed services to students and faculty.

View from campus Quadrangle.

Planning Process

The college began the initial planning of an extensive renovation of and addition to the areas housing the Departments of Biology, Chemistry, and Physics, and the Science Library. A Science Building Planning Committee, including representatives of each of the departments, the library and the staff was appointed by the college president. The committee started by asking each department to define and describe the types of spaces it would ideally like to conduct its program, without regard to the existing building. The committee attempted to coordinate the process and to consider spaces used by all departments and/or the broader college constituencies. Fairly early in the process it became clear that those idealized space requests would have to be pared down to allow a project of practical proportions. Even after scaling down the number and size of rooms, however, the scope of the project remained roughly twice that which the college had anticipated. This seeming impasse was resolved by breaking the project into two stages, the first (to begin construction in summer 1995) to include primarily renovation and a modest addition, and the second (to be constructed subsequently) to involve demolition of the one-story wood-framed wing and construction of a three-story structure in its place. Both stages have been planned through design development, to assure consistency between the two stages.

Project Goals

1. Design spaces that support the educational philosophy of the science departments, including provision for active learning in the classroom, discovery-based learning, use of state-of-the-art instrumentation and technology, and space to support student-faculty research.

2. Design spaces that promote and support a sense of community among faculty, students, and staff.

3. Provide additional space to alleviate current overcrowding.

4. Provide space for a modern science library including effective use of electronic access to information available both on the campus and through national networks.

5. Improve the building's accessibility to persons with disabilities.

6. Renovate mechanical systems so they will be adequate and reliable.

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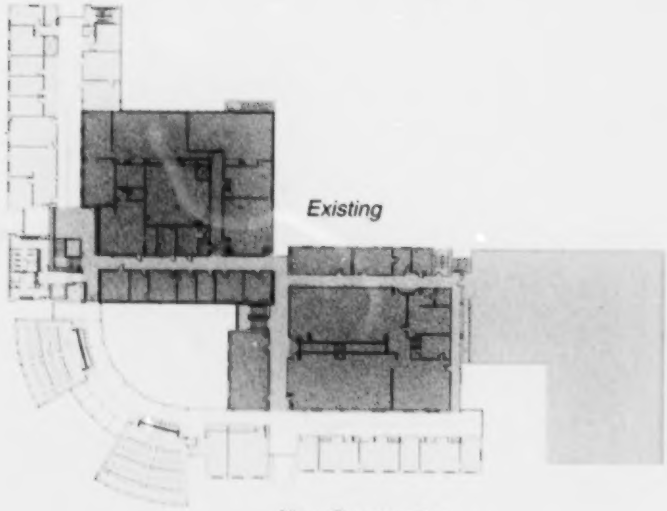
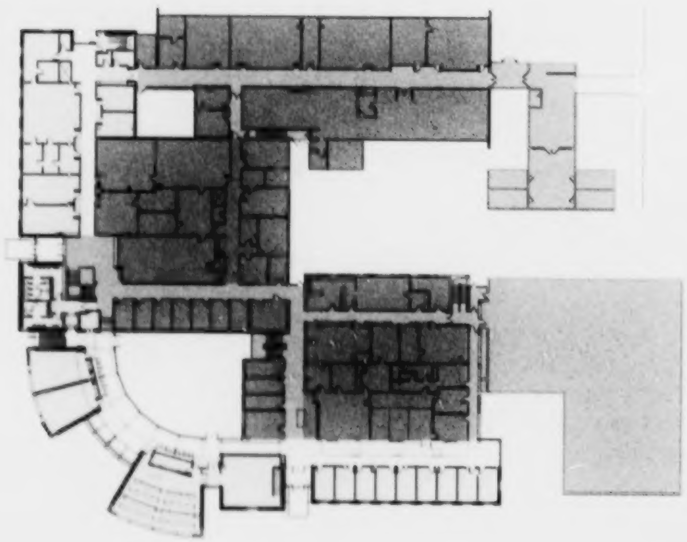
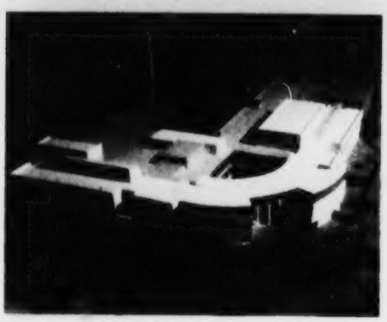


Second Floor Plan



First Floor Plan



Aerial view of model.

Project Design

Specifics of design will include an addition wrapping around the 1952 and 1965 wings, unifying them, and providing a new exterior to the building. Large clerestories and glass connecting walkways will introduce natural light into a rather large structure and make science visible to those outside the building. Large classrooms will be tiered for good lines of sight, using two rows of tables per tier so that students can work on problems in the classroom in groups around a table. The tables will be arranged and wired to allow the use of networked notebook computers during class sessions. Biology research laboratories will be clustered around instructional laboratories, to allow use of specialized equipment in the research laboratories by students during class sessions and expansion during the summer of research into the instructional laboratories. The first two years of chemistry instruction will be enhanced and supported by a complex of four rooms, including general and organic chemistry laboratories, an instrument room, and a room equipped for discussions and data analysis. Advanced physics laboratories will be adjacent to student study space to promote a sense of community and will be moved to a more prominent and visible location within the building. Computers in all areas will be networked to allow access to local databases, Internet, and other bibliographic databases such as Chemical Abstracts. Numerous clusters of desks, tables, and chairs will be provided in widened areas in circulation spaces, further enhancing opportunities for interaction among students and faculty.

> **It is important to the vitality of teaching in mathematics, science and engineering, therefore, that the best of new programs become known, and seriously considered for adaption, where appropriate, for use at other institutions. Faculty in other departments and at other institutions must learn about the best of the innovations and must have access to the financial and human resources needed to evaluate and adapt worthy ideas to other settings.**
>
> —*NSF Report, NSF 91-21.*

Focusing on What Works.

Such stories are illustrations of how transforming program and space go hand in hand, and they are being enacted on campuses across the country. Institutions of all sizes and in all sectors are beginning to explore why and how to translate their mission into better environments for learning for their students in science and mathematics.

Focusing on *what works* in curricular transformation in other settings is a helpful next step in your facilities planning process. By talking with colleagues on other campuses who are actively involved in curriculum reform efforts, and/or who have been involved in recently completed facilities projects, you will gain important perspectives on what will work and what might not work for your campus community. On each visit, talk with as many persons as possible, including students. Bring a camera.

In industry, such cross-pollination is called "benchmarking," an occasion to learn about what others are doing and to evaluate possibilities for local adaptation. Benchmarking is a critical step in facilities planning, and such trips should be encouraged at an early stage in the process. Remember, there are no intellectual property rights on good ideas in higher education.

As you visit other campuses, keep in mind you are there to gain ideas to *adapt* for your local circumstances; institutional circumstances differ, thus you should not be planning to *adopt* what others are doing. Ideally, it helps to visit both institutions with a similar identity and mission, and those with distinctly different missions. (See Appendix for a Listing of PKAL Programs that Work.)

Remember that the process of planning is an evolutionary one, and that each separate activity, such as visits to campuses and departmental meetings on curricular dreams, will be repeated at different stages during the months and years of planning, by different individuals and groups.

As the process becomes more formal, develop a standard list of questions to ask during such benchmarking visits, such as the following questions on planning facilities:

- What most influenced the design? What do you like most? What do you like least?
- What would you do differently now? Any surprises? Any failures?
- How was it decided to build new/renovate?
- If new: what influenced the site selection? How will the old space be used?
- How was the campus planning team (the Building Users committee) assembled? Was there a project shepherd and/or project manager? What staff support was necessary?
- How were decisions made and communicated throughout the process? How was the budget determined?
- How were the design professionals and construction firms selected? Were they responsive to your needs? Was it easy to be a good client?

As you make these benchmarking visits, there are also important questions about *why and how* program and space have been transformed:

- What drove the decision to make changes in the curriculum?
- What drove the decision to make changes in the spaces?
- What kind of learning environment were you working toward? How important were undergraduate research, hands-on learning, use of technology, etc.?
- Did this project involve one department or several?
- What fields within the disciplines are represented in the department(s)?
- Is there now a different balance between lecture and lab, demonstration and discussion?
- How did departmental offerings shape the new spaces; what was the impact of the new spaces on departmental offerings?
- Has interdisciplinary activity been facilitated by the new program or new spaces?
- In what new ways are computers and technologies being used? Can you make use of multimedia technology from your classrooms, seminar rooms, and labs? Do labs accommodate computers for real-time data acquisition and analysis?
- How sophisticated is the instrumentation available for your students and faculty? Where is it located?
- Do faculty and students have access to all major instrumentation without disturbing others?
- Can your students run multi-week projects?
- Can lecture classes break into small group work? Do furniture and layout allow students to work in teams during laboratories?
- How do the traffic patterns work between offices, research space, classrooms, and informal spaces?
- What has been the overall impact of the new space on teaching, research, sense of community?

These are the kind of questions that might be used also at your home campus to identify problems and potential with your current space and program.

No area is more important than the mission of a college or university. The mission statement should embody the vision held for its future by the board of trustees, government agencies (in the case of public institutions), the president and staff, the faculty, and other constituents. The mission of any institution of higher education reflects the proper balance for that institution of a concern for the individual development of students, the advancement of knowledge, and service to the community—or for instruction, research, and public service.

The institutional mission, when it is well prepared and well understood, incorporates and reinforces the identity of the institution and specifies its distinctive features as compared to other institutions.

Mission statements should be reviewed and updated from time to time to ensure that they are current, clear, and accurate. A proper mission statement should be broad enough to empower the board and the administration to embark on desirable activities, but it should also be specific enough to offer a clear sense of vision, direction, and focus.

—*Strategic Decision Making*, *Association of Governing Boards*.

Conclusion. Keep discussions at these early stages open and free; they should be wide-ranging, involving many different members of the community. Explore many different ideas about the future of both curriculum and space for your undergraduate programs in science and mathematics, ideas that have been stimulated by thoughtful consideration of your mission as a campus community, by your benchmarking visits to other institutions, and by personal reflection on what it will take to improve the environment for the natural science community on your campus.

This is the time to be both visionary and realistic in your dreaming; the new spaces and structures being considered will serve the institution for many years. Remembering that the goal is to improve learning for students, think about questions such as the following:

- What works in the science and mathematics programs on our campus?
- Is undergraduate research to be a hallmark of all our programs in science and mathematics?
- What will be the impact of emerging technologies, with enormous databases on- and off-campus, on our programs?
- What will be the impact of the increasingly interdisciplinary nature of science on our programs and space?
- What kind of trade-offs should we consider between hands-on activity and computer simulations for labs?
- What kind of spaces are needed for faculty to remain vital as scholars?
- Are there ways, intellectually and physically, that new connections can be made between the sciences, and among the sciences, the humanities, and the arts?
- What impact will the increased attention to a technologically sophisticated work force have on our program?
- How will the increasing national attention on developing a science-literate citizenry, transforming the K-12 community, bringing groups currently underrepresented in science, mathematics, and engineering affect our planning, our program, our space?

Such questions will be addressed in more depth during the process of defining the facilities program, after the decision has been made to move ahead with your project.

Answers to these questions will differ campus to campus, as individual institutions explore them in the context of their distinctive identity and mission. However, even if a major facilities project is not anticipated, these are the kinds of questions that must be asked as each academic community prepares to build and sustain strong undergraduate programs in science and mathematics in a changing, challenging world.

CHAPTER II: FOCUSING ON THE CAMPUS

Introduction. What is a campus? Significantly, the campus is the stage setting for the life of your community; the campus is the *common ground* that unifies the diversity of activities in which students and faculty are engaged, and the diversity of buildings in which those activities take place. On a campus built over the years, this common ground brings order and stability to the diversity that has accompanied such growth and change. The common ground that is your campus should make sense from the symbolic, educational, aesthetic, and functional perspective. It should have such strength and clarity that each building proclaims its own individuality, yet at the same time contributes to the greater collective good.

All individual buildings on a campus have a physical as well as a curricular context, yet (unlike regularly recurring discussions about curricular issues) rarely do campus communities come together to consider how the campus as a whole *works* for them. As you now think about structures for science (a possible new building, an addition to or renovation of existing spaces) at your institution, it is essential to consider both *campus* and *curriculum* from the perspective of mission, strategic goals, and priorities, and to reflect on the social aspects of architecture. In fact, curricular planning and campus planning must be woven together over many months until you come to final decisions about the building: how it will function, how it will look, and where it will be placed.

Architecture and Community. The importance of maintaining a focus on community and on the social aspects of architecture when designing academic buildings cannot be overstated. As you make benchmarking visits to other campuses, notice whether and how they *work* for the communities they serve, whether and how they provide a common ground that brings a sense of rationality and hospitality to the environs. Consider how the proportion and scale of buildings and open spaces, as well as the rhythm of openness and boundaries, work to organize the space in which those campus communities function in a meaningful way.

Walk around and through the buildings and open spaces on your own campus. Observe how buildings planned and built in earlier eras, which reflect the ideas and values of different times, come together in a coherent pattern and serve as an appropriate stage setting for the life of your community today.

As you walk through your campus, ask:

- How does the campus reflect our particular academic traditions?
- Does the campus reflect the values of our community today, and our vision for the future?
- What are the best, the strongest characteristics of our campus that should be preserved and extended?
- Which are the buildings that alumni return to again and again?
- Is there a *sense of place* that brings life and meaning to our community?

Man dwells when he can orientate himself within and identify himself with an environment, or, in short, when he experiences the environment as meaningful. Dwelling therefore implies something more than "shelter." It implies that the spaces where life occurs are places, in the true sense of the word. A place is a space which has a distinct character. Since ancient times the *genius loci*, or "spirit of place," has been recognized as the concrete reality man has to face and come to terms with in his daily life. Architecture means to visualize the *genius loci*, and the task of the architect is to create meaningful places, whereby he helps man to dwell.

—Christian Norberg-Schulz; Genius Loci, Towards a Phenomenology of Architecture.

ARCHITECTURAL ELEMENTS AND MOTIFS: MATCHING A CAMPUS

The Duke University Story

Our goal was to have a facility that would be a centerpiece for scientific research and education at Duke, a multidisciplinary building that would enhance the interaction and cooperation between faculty and students, and that would ensure the sustained growth of research in several areas. The recently dedicated 200,000 net square foot building went through several stages in the process of planning to achieve that goal.

In the first stage of our planning, in the mid-1980's, ideas surfaced about a separate "technology center" which would focus research space and programs around opportunities for commercialization and technology transfer. To house this center, consultants proposed a separate building in which applied scientists, engineers, and their industrial partners would work, and a series of small annexes to existing facilities for biology, chemistry, and engineering to house faculty offices. This proposal aroused many concerns, as the placement of the technology center would have widened the gulf between the main campus and its research facilities rather than narrowing it; more importantly, it would have widened the gulf between departments and reduced the possibility of expanding the interdisciplinary research programs in ways desired by faculty.

In response to such concerns, a committee of faculty and administrators was appointed with the charge to develop a proposal that would address, in location as well as in spirit, the research and educational goals in regard to interdisciplinary programs that had been established by the community. As the work of this committee proceeded, it became clear that the new facility would provide an opportunity to build bridges (symbolically and literally) between Duke's medical and non-medical research programs, and thus reduce barriers between the scientific disciplines and medicine on the campus.

The final location of the new facility, on the axis linking the medical school and existing research buildings, clearly serves that dream. The building is designed in a "T" shape, with a central common space called the *Hall of Science* through which all students and faculty pass to and from classes and labs. The new facility also houses the first public eating space at Duke not in a residence hall.

The new facility contributes to the physical integrity and coherence of the Duke campus also in other ways. When the architects began their work, they took note of the features that distinguished our physical environment, principal of which were the quadrangles and the walkways leading to, through, and from the quadrangles. How

people get around is important on this campus. An equally important persisting architectural feature is that there is enough space between buildings so that each has its own architectural identity; as the walkways thread through Duke's quadrangles, they lead through spaces between the buildings wide enough to reveal the towers and shapes of academic buildings in the next quad.

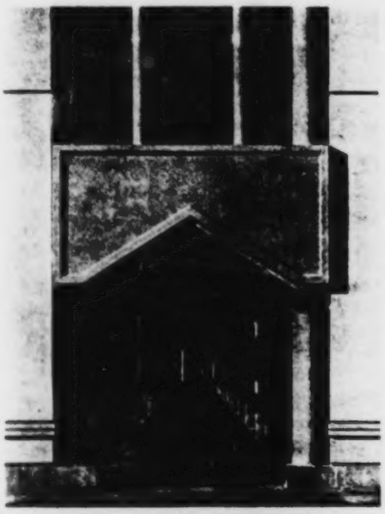
However, despite the individuality of its buildings, the campus is no hodgepodge. Architectural elements and motifs have brought a sense of unity to the Duke campus—linking individual buildings with each other and with the open campus spaces. This is the case even though there is an architectural tradition at Duke that individual buildings reflect the special individual qualities of the discipline or department housed therein.

Within the boundaries of these unifying principles—quadrangles and walkways, spaces and forms that tell a story—the architects planning the new facility were challenged (and given the freedom) to design a highly individual building that had visual impact, said "science," and ultimately added to the cohesion of the campus.

In connecting the new building to the existing campus, architects designed the building's most commonly used entryway to be the one that looked toward the campus, not one that looked toward a parking lot. The building itself was situated so that it formed a side of a new, informal quadrangle looking toward the older campus buildings. Low, curved, stone walls were built on the grounds and around the stairwells of the building, repeating similar stone walls throughout the campus. Protruding concrete archways around corner stairway towers and entrances and low, wide stairways to the entrances, repeated other Duke architectural themes and thus contributed to the coherence of the campus. The outdoor spaces near low walls are efficient exterior science classrooms, and the spaces between the adjacent buildings are as open and enjoyable as those in the older part of the campus.

At Duke, thinking about the spaces between the buildings and how people moved to and through the building was as much a part of the project as was thinking about what was to happen inside. The success of the process was due to the active and carefully coordinated involvement of faculty, administrators, trustees, and architects. Each brought to the process particular expertise and intelligence about possibilities; all of us were open to creative ideas as they came to the fore.

Our mutual goal was to integrate the design of the building fully into the life of the community—from the perspective both of academics and architecture. We succeeded.



Your campus as well as your curriculum can be a clear expression of how your community asks and answers questions about the purpose of the enterprise: how you understand the relationship between *how* and *what* and *where* students learn. If, as we in PKAL believe, the planning of new spaces and structures for science can be a defining moment, then this is an opportunity to step back and reflect on the physical setting into which such new spaces must fit.

Ask:

- Do buildings, individually or collectively, serve as centers of intellectual and social activity?
- Is there an inherent unity, integrity, and coherence to our campus, or does the placement and character of the buildings, walks, and roads suggest that decisions over the years have been made in a piecemeal, *ad hoc* fashion, building by building?
- Can a new facility reinforce what works now in campus patterns and anticipate new patterns that will accompany future growth and change?
- Should a new structure be an opportunity for redefining "centers" on our campus?
- In what ways might the new facility or renovated structure remedy past mistakes in campus planning?
- How can we be certain that a new building enhances the unity, the *common ground*, that we already have?
- In what ways might the structure we are now planning become a physical expression of our vision for the future of our institution?
- Can the landscape design be used as an educational tool for students?

Answering such questions helps to determine what must be done and what must not be done, as well as what would be nice to do, in regard to the external physical characteristics of the building you are planning. If there are architectural characteristics that make your campus distinctive, make a point of considering them in the design of a new science facility. What does not work, what does not foster unity, or what appears not thought through or the result of random decisions, you should avoid and not repeat.

Whether you are building anew or renovating or adding to an existing building, you must think through siting issues from the perspective of the tangible impact of the proposed structure on campus circulation patterns and on its relationship to open spaces and other buildings. You must also consider the less tangible, but no less real, impact that the new structure will have on the order and stability of the common ground that is your campus.

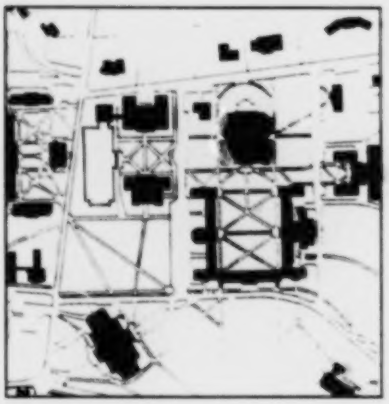
Site. There are three fundamental issues that must be addressed in selecting possible sites, whether you are planning a new facility, a major addition, or renovation of an existing structure: symbolism, stewardship, and value. What works best is a site in which all three come together in a manner appropriate for this time in the life of your institution.

It is important to begin thinking about siting by understanding the symbolism of a building.

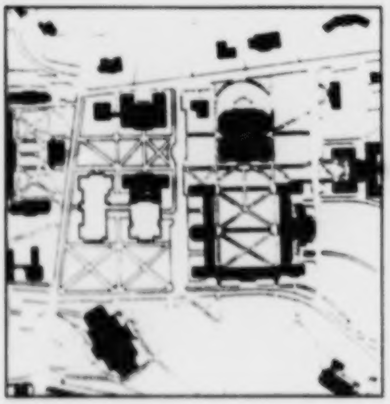
- From the perspective of institutional mission and plan, how important is the building? Is this to be a flagship building? *If so, the site needs to be prominent, noticeable from major points of campus access, large enough to show off the building (perhaps by having a garden or open space in front and around to set it off).*
- Is it to be a gateway to knowledge? *If so, perhaps the best location is near the library.*
- Is it to be a magnet for interdisciplinary exploration, or a link between the sciences? *If so, a site near, or a connection to, other science buildings might be appropriate.*
- Is the mathematics program to be housed in the new spaces? *If so, ask if the building might be placed in a way that identifies mathematics as a language to be learned by all students, not just an elite tool to be used by scientists.*
- Will the building serve as a bridge between the science and nonscience programs for an expanding program of general education? *If so, a central campus location may be important: perhaps near the performing arts or student activities center.*
- Are programs of outreach to the K-12 community of increasing interest and importance to your faculty? *If so, the building might be sited in a manner that offers easy hospitality to those off-campus educational communities.*

CAMPUS SITING AND PLANNING

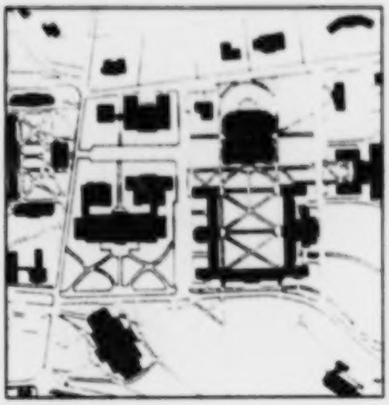
The Bucknell University Story



Bridge



Pod



Gateway

The goals of planning for Bucknell's science center were to:

- ◆ strengthen the identity of the sciences on the campus
- ◆ reinforce campus circulation and organization patterns
- ◆ complement the scale and character of existing buildings
- ◆ encourage interaction among departments, faculty, and students
- ◆ consolidate the sharing of facilities among the sciences
- ◆ facilitate phasing, flexibility, and efficiency
- ◆ address critical health and safety issues.

The 300-acre campus is characterized by traditional Georgian architecture and broad, formally developed quadrangles. The quality of the spaces created by the buildings is as important as the buildings themselves. Planning and siting proposals went through several metamorphoses before we arrived at the final scheme.

The first plan, *the bridge scheme*, proposed a new structure for the disciplines of chemistry, biology, and psychology that would serve as a bridge connecting the existing engineering and computer science buildings to the building that housed physics and math. While highly efficient from a lab planning perspective, it became known as "The Great Wall" because of the massive impact of the new structure on surrounding buildings.

The second plan, *the pod scheme*, proposed to break the complex into discrete "pods," making the scale more compatible with existing campus architecture. Although this scheme was more easily phased and thus more fundable, from a laboratory planning perspective, it was inefficient and inflexible.

The final scheme, *the gateway scheme*, solves both campus and laboratory planning issues. Through its central rotunda, it also creates a strong visual identity for the sciences from the proposed main campus entry, as well as a formal "gateway" to the science and engineering quadrangle.

Campus design is the art of campus planning, the culminating act of those processes and procedures that give form, content, meaning, and delight to the physical environment serving higher education. Designs that are created can define and celebrate a sense of place; communicate an institution's purpose, presence, and domain; and generate an image charged with symbolism, graced by history....Colleges and universities cover a broad range of human activity and habitation. Whether new campus or old, each institution deserves to be shaped by a plan that is responsive to its own realities, marked with its own distinctions, and guided by concepts that are as workable as they are attractive.

—Richard P. Dober. Campus Design.

After thinking about the symbolic value of the siting of your new facility, you must consider how the site will serve your community, about the stewardship of the site. Here issues such as circulation, connectivity, open spaces, orientation, and future growth will be important.

- Is the building to be an integral part of a larger complex, a piece among many that holds together the campus puzzle? *If so, in siting the building consider its connection to those other buildings, so as not to cut off sources of natural light or interfere with pathways, outdoor spaces, vistas, or other elements held in common.*
- Is it important to reinforce existing circulation patterns? *If so, think about how to build "bridges" between centers of intellectual and social activity.*

Consider circulation patterns on your campus, how people use foot, bike, and vehicular traffic to move to and through the spaces. (Even such a mundane question as where the loading dock would have to be in regard to traffic patterns for each proposed site needs to be asked.) As you consider various sites, ask if principal pathways have to go around the building, pass it by, intersect—or perhaps just stop at the new facility? Ask how the building will be used:

- Is it your dream that students will come in greater numbers, attracted by the sense of excitement generated by the new spaces? *If so, the location must be welcoming for all, with easy access to the building by bicycle, on foot, or by car, with a clear access to the entrance.*
- Will this building serve the entire campus community, providing lecture halls, seminar rooms, libraries and/or computer labs that will be available regularly for use by students and faculty beyond science and mathematics? *If so, ease of access (and visibility) from different parts of the campus is desired.*

Just as important as circulation patterns are the ways that a new building makes connections to existing or future buildings and to the open spaces on your campus.

- What works best for your community in moving between and into buildings? Is it important to be indoors; will bridges or tunnels between spaces serve your purposes?
- Where are the places that people meet each other? How, in the siting of the building or in renovating an existing structure, can community be fostered? *You may decide to use outdoor spaces, such as courtyards, or perhaps bridges between buildings, as places for the informal interactions important for the study and doing of science.*
- Will there be a comfortable relationship between the landscape and the building? *Your goal should be a site that invites interaction with the people and the activities within.*

Sometimes completing the open spaces is as important as constructing a new building. Perhaps it will work best for you to place a building so it completes a quadrangle, or completes a streetscape by filling in a space between two existing buildings. Over time, a campus inevitably becomes overcrowded with structures, and in extreme cases, taking down a building may be the best way to find a new site. Sometimes it is important to create open space for its own sake, to create a more environmentally balanced campus. Indeed, a good rule of thumb is to include green space as a part of every building project. This way, buildings can expand easily, a land bank is created for future buildings, and landscape becomes an integral part of the physical environment.

Openness and hospitality are hallmarks of a campus that functions well. Thus orientation, getting around on the campus easily and without confusion, is a very desirable objective. Identify the vistas that are important both looking outward from the site and into the site from the campus.

- Are there important *view corridors* and axes to reinforce, or landmarks to view that make your campus distinctive?
- Are there natural features in the campus landscape that can be highlighted to help people recognize where they are and where they want to be? Will parking spaces be displaced? Where will they be relocated and how can they seem integrated so to be inobtrusive?

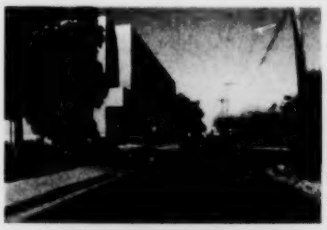
Current "view" orientations may change as the campus continues to evolve, so you must also consider possibilities for future growth. Look

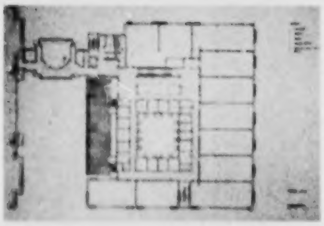
How to Get a Good Building: Process and Ideas

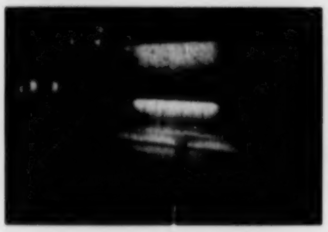
College of Architecture and Environmental Design, Arizona State University

Creating Comments. A 100,000 square foot expansion of a 50,000 square foot building—across a public right-of-way that had to be maintained. A bridge/building connects new and old across and facing a new campus piazza created in the old street—a place of outdoor community.

Inside, the lecture rooms, library, faculty room, and administration surround and overlook a community court at the heart of the building. The space was created out of intelligent program "interpretations." It brings life to the school.







at a site and ask if it will be the right place over the long term.

- Are there utility easements, tunnels and networks in place for future expansion? Are open spaces available to accommodate new buildings in the future?

Finally, in considering possible sites, you must consider value and thus find practical solutions to site problems from the beginning. A large part of the budget can be buried, literally, underground. For example, you can locate the shortest route for utility hookups to the building; you can find the firmest soil to place the foundations on.

Keep the building footprint away from floodways and wetlands; keep the basement above the water table. Locate the building so that exhausts do not have a negative impact on the fresh air intakes of nearby buildings. Keep windows away from the night sky of campus observatories. Most important, keep hazardous waste in controlled storage areas, especially if located underground.

Increasingly, what are being called *sustainable design* issues are receiving attention from campus communities and campus planners. How you place the building can make a difference in the use of energy, as you plan (or do not plan) to make optimum use of passive solar energy, and/or natural wind patterns to conserve energy. The impact of the building (from the process of construction through use) on the natural environment should be minimal. The nature of this impact can be mitigated in several ways, from preserving natural features of the site to establishing staging areas and travel routes for construction vehicles. For urban campuses, the need for and availability of public transportation may be a factor in where the building is to be sited to address broader concerns about energy consumption.

Perhaps more so than for any other building on the campus, addressing sustainable design issues in the process of planning a facility for science can be symbolic as well as good stewardship and giving attention to value. Budget officers as well as students will be interested in working on sustainable design issues with you. Your decisions in this regard might also be of interest to prospective donors interested in making an investment that makes sense both for the short- and long-term of your institution.

By thinking about vision, stewardship, and value as you consider each possible site, you will be able to make the right decision and make a positive contribution to the common ground that is your campus.

Planning is important, but a plan without a well-defined goal is virtually useless. Too many times facilities administrators have an idea of where their campus should be headed and what needs should be addressed, but a definite goal has not been pinned down with endorsements from representative constituents. The process may begin as a general plan for expansion and development, but since some elements are unclear, such as academic programs or enrollments expectations, the purpose of the process becomes lost or questions are raised regarding the original intentions.

As unproductive as the absence of planning may be, a planning process that is unfocused or poorly directed will yield poor results. If there is no goal, constituents within the institution who were asked to help with the plan may begin working at cross purposes, and wasting time, money, and resources.

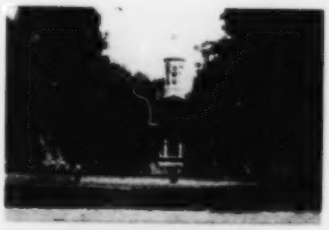
Sometimes goals are not as obvious as one might think. An important part of the process is to take some time to consider all possible objectives the master plan needs to fulfill. Determining the final destination is essential to begin contriving a plan that hits the mark.

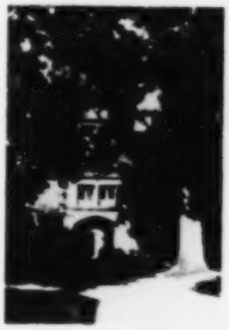
—*Planning for Master Planning*, APPA, 1995.

How to Get a Good Building: Process and Ideas

Princeton University.

A most characteristic American campus. It began with a single building, Nassau Hall, that housed the entire original College of New Jersey, including horses in the basement. Over time Princeton's expansion was largely idiosyncratically planned, with some localized areas of formal development. Today's widespread campus can be "read" sequentially, its parts reflecting the values of the time of their creation. It is a rich amalgam that includes a period of modern architecture when campus planning was largely misunderstood or disregarded. In recent times Princeton's planning has been exemplary of a clear understanding and extension of its best and strongest characteristics.

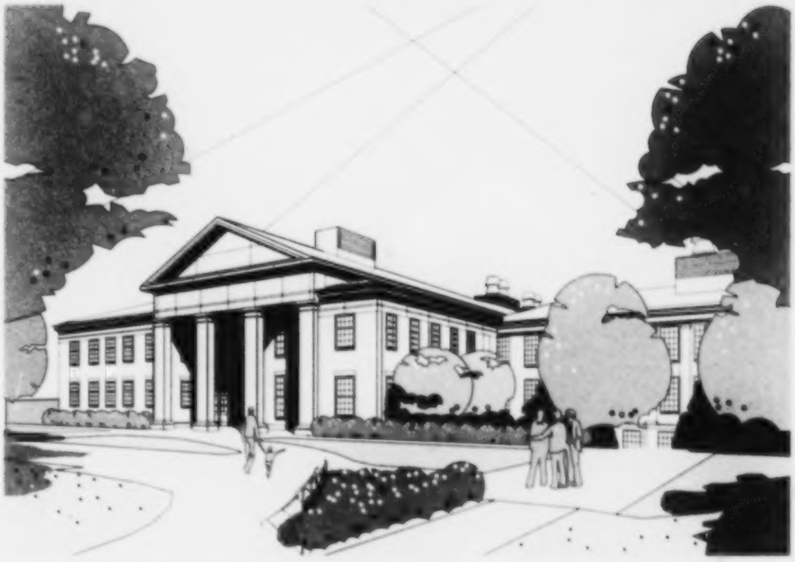




Washington and Lee University Science Center

Lexington, Virginia

Architect:	Payette Associates, Inc. Boston, MA
Lab Design:	Payette Associates, Inc. Boston, MA
Size:	
New Construction	83,000 GSF
Renovation	93,000 GSF
Construction Cost:	$18,600,000
Delivery Method:	Construction Manager
Net Square Feet:	
Biology	16,840
Chemistry	15,460
Common Space	2,300
Computer Science	2,200
Geology	10,275
Physics & Engineering	11,275
Psychology	8,175
Science Library	10,200
Shared Instruments	9,000
University Classrooms	9,460
Animal	1,510
Total	88,595
Net/Gross Ratio:	50%
Completion Dates:	
Addition	June 1996
Renovation	August 1997
Building Population:	500



The new portico creates a single symbolic entry for the Science Center which reflects the architectural context of the campus.

Budget and flexibility requirements required a modular approach to the design of the teaching labs.

Washington and Lee University, a liberal arts institution with under 2,000 students, intends to strengthen its undergraduate science program by making major improvements to their two existing science buildings as well as constructing an addition which will create a single Science Center complex. The new center will contain the Chemistry, Geology, Biology, Physics and Engineering, Psychology, and Computer Science Departments. Additionally the six independent departmental libraries, presently located in separate buildings, will be combined into one unified library as a focal point within the new Science Center.

The traditional classical revival architecture of the campus presented a familiar challenge to the architect and campus planners. The facility must be harmonious with the existing character of the campus while still managing to create a technologically advanced Science Center that embraces the future.

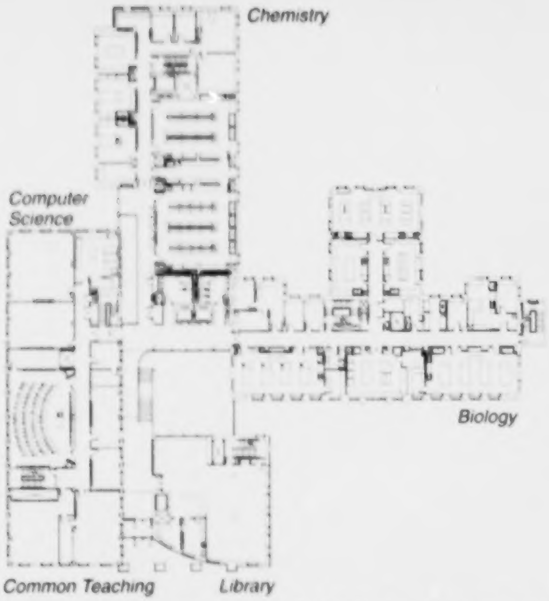
Design Principles

Working with a program document prepared for the university by Dober, Lidsky, Craig and Associates, Inc., the architect, Payette Associates, developed a three-stage phasing strategy that eliminates double moves and renovation around occupied space. The addition will contain the hood-intensive chemistry department on the upper two floors and geology below. When these two departments move into the addition, Howe Hall can be gut renovated. Once completed, biology and physics move into Howe. Parmly Hall, the final phase, can then be gut renovated for psychology and computer science. The scheduling of the construction around the academic calendar with summer moves allows for minimal interruption of ongoing classes. This phasing strategy allows for more new space and less disruption by not wasting time and money on double moves and difficult scheduling around ongoing occupancy in existing buildings. Budget and flexibility requirements required a modular approach to the design of the teaching labs.

The planning principles for the departments varied slightly but all called for a strong adjacency of teaching lab to research lab to faculty office. Separate office zones were discouraged in favor of accessibility for students to the faculty throughout the various departments. In the new addition the chemistry and geology teaching labs and support spaces were located on one side of a double-loaded corridor with research labs and offices located on the other side. The central core of the addition contained the ADA accessible elevators and toilet rooms. The 1925 Howe Hall accepted a certain amount of modular renovation for biology and physics, but the 1962 Parmly Hall was less flexible and lent itself to the less modular psychology and computer science programs.

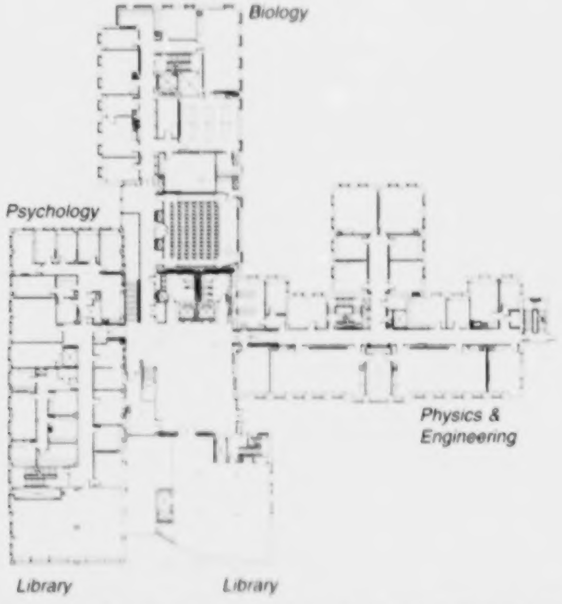
Science Center Organization

The new Science Center is organized by a central circulation spine and a Great Hall from which students can access the six departments. The library is in a "Head House" at the main entry

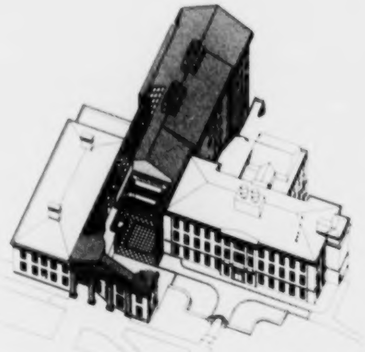


Second Floor Plan — The Great Hall, centrally located on the second floor, provides a major interaction space for the Center.

The rear elevation acts as a service access with a hazardous storage facility.



Third Floor Plan — The main entry off of Stemmans Plaza unites the Center to the campus.



The new addition is inserted between two existing buildings.

and is the symbolic and literal focus of the Center and Great Hall. Additionally the library's location encourages non-science majors to visit the Center by creating views back into the Great Hall. Along with these communal spaces there are centrally located shared-instrument rooms, university classrooms, and computer labs. They are all accessible to each of the six departments and the general student population in order to facilitate interdisciplinary studies within the sciences and the university at large.

Interaction

The Great Hall was designed as the major interaction space in the Center; the "Front Door" to all the departments are off this space. The library, which overlooks the Great Hall, was programmed to facilitate learning for various sized groups, single study carrels, double study carrels, round tables for four, and several small meeting/study rooms. Additionally, corridors were designed throughout the Center. Many of these areas have blackboards and seating to facilitate impromptu discussions.

Safety

Special attention was paid to visual transparency between the teaching research spaces and the built-in safety features. Waste stream management considerations designed into the facility early in the process made sure ample space was provided for storage and disposal of hazardous materials.

The architect developed a three-stage phasing strategy that eliminates double moves and renovation around occupied spaces.

Campus Master Plan.

Considerations of possible sites must be undertaken with the advice and counsel of staff from the campus facilities office. Moreover, campuses undertaking major projects frequently engage the services of an external consultant to develop a campus master plan that sets the parameters for site and building related influences, including location, traffic patterns, phasing, circulation, massing, growth, and landscaping over time.

The campus master plan is the document that articulates a specific view of your campus environs: how land use, circulation, parking, building use, landscape, infrastructure, and any other concepts or components of the campus layout will be developed over a ten- or twenty-year period. On some campuses, such master plans are live, working documents that shape ongoing decisions about use, maintenance, and development of the physical plant. On other campuses, such plans are out-of-date, or used only periodically. When considering a major investment of dollars and time in a new science facility, it is imperative that the campus master plan be revisited and/or reshaped, in much the same way that the academic plan of the institution has been.

As the academic plan sets an agenda for curricular reform, so the campus master plan lays out the long-term aims and objectives for the physical development of your institution; it also lays out the framework for the decision-making to achieve those aims.

The first step in developing both the curricular plan and the campus master plan is to identify, analyze and confirm assumptions about present and future numbers of faculty, students, and staff, and to document the present and anticipated nature of the curriculum and pedagogy. In campus planning, the next step is to evaluate the physical condition and functional adequacy of all buildings and environs, making a record of their characteristics, existing conditions, and use. This information is used to document whether current or planned facilities can support institutional programs, those you now have and those you anticipate in the future.

From the foundation of these analyses, you will move through the sequential planning stages to develop and consider options, and to determine, develop, and implement the most feasible plan for your physical environment.

In developing or revisiting your campus master plan, the continuing use or reuse of existing facilities and spaces will be outlined toward the goal of an attractive and functional physical environment that serves the community for many years. Appropriate sites for enhanced landscape development and for new construction will be identified, together with a proposed sequence of changes in the physical character of your campus. The plan will also include cost estimates for each change.

Although you may be making or remaking the campus plan specifically for the purposes of planning a new science facility, be mindful that just as considerations of curricular reform proceed best if a broad constituency is involved in the planning, so too does engagement of the entire campus community assist in making a campus master plan workable and enduring.

THE SCIENCE FACILITY IN CONTEXT

The Campus Planner's Perspective

A campus plan is a comprehensive point of view about an institution's future intentions for maintaining and developing its physical resources. It must be strongly rooted in mission, academic plan, and financial resources. In order to be effective, it must be developed through a participatory and collegial process. The plan must also be founded on approved projections for number of faculty, students, and staff, and based on both an understanding of present curriculum and programs, as well as future initiatives.

Campus plans are often used to inform a development effort, and documents prepared during the planning process can be used for fund-raising. Some foundations and funding agencies are beginning to insist that projects fit within the context of a campus plan.

During the campus planning process a decision will be made about how much additional space is appropriate, and whether constructing an addition to an existing science building or constructing a new facility is the desired alternative. At this time, an appropriate site will have been chosen for any new space. Other institution-wide issues will have also been resolved, such as the number and size of classrooms to be provided. (Remember, classrooms are an institutional resource, and their provision and use should not be determined by individual departments.)

Questions about the future number of science faculty and students can be answered only in the broader context of the college or university's long-range plans. The institution should have a point of view about projected enrollments and numbers of majors within an agreed upon time frame: 15-20 years, for instance.

Relationships between science disciplines have changed dramatically in recent years, as have the interrelationships between the sciences and other institutional programs. Disciplinary boundaries have become less distinct between the sciences. Affinities between the sciences, the social sciences, and the arts and humanities are evolving, and institutions are trying to strengthen and encourage these ties. Programs such as environmental studies, molecular biology, computational biology, and neuroscience, which bridge academic divisions, should be coordinated through campus-wide planning.

Colleges and universities should be sensitive to the timing of campus improvements. How much lead time will be required for new or renovated space to become available to different user groups on campus? The process of completing new or renovated facilities could take seven to ten years. For a department scheduled for facility improvements at the end of the cycle, that period will seem like a long time to wait, and some departments may not be scheduled for improvements at all. There is the potential for faculty and students to perceive a three-class society: those with improved facilities, those to be improved, and those with unimproved spaces. This could affect morale, and have a detrimental impact on the quality of instruction, as well as on the number of student majors. One strategy that the college or university can use to minimize this problem is to launch a series of campus-wide classroom renovations. Renovations can include new carpet, paint, furniture, network wiring, and multimedia equipment. This is an easy way to enhance the teaching and learning environment for the greatest number of faculty and students on campus.

The campus plan is as much a process as it is a product; it must support the established academic plan, as well as be flexible enough to provide for the changes in program, curriculum, enrollments, and priorities that will occur over the planning time frame. Only by understanding the broader perspective, can an institution ensure that the specific needs of the sciences are appropriate and fit within the institutional mission and vision—it is then the facility improvements and programmatic initiatives are a true bridge between the past and the future.

University of California-Riverside Engineering Science Building

Riverside, California

Architect: Anshen + Allen Architects
Los Angeles, California

Size: 164,650 Gross Square Feet

Construction Cost: $28,700,000

Net Square Feet:

Laboratories	61,400
Lab Support	11,500
Offices	24,875
Classrooms	6,625
Total	104,400

Net/Gross Ratio: 63.40%

Completion Date: April 1995

Design Period: 24 Months

Construction Period: 23 Months

The courtyard between the office building and the laboratories opens to an extension of the Commons Mall.

Background

The University of California, Riverside campus was first developed in the 1950's, and has remained largely undeveloped since its initial building program. The new College of Engineering, the first new engineering school to be developed in the state in 25 years, is the flagship project of a new campus growth phase necessary to support a student population that is projected to quadruple in the next ten years.

The campus structure is organized around a central mall that leads to informal linked courts formed by two- and three-story brick and concrete buildings. The architectural expression of the core campus is characteristic of the 1950's. The buildings are almost neutral backdrops for the landscape which is the dominant character-defining element of the campus.

Planning

The new College of Engineering was master planned as a phased development to eventually total 600,000 square feet. Located at the perimeter of the core campus, the complex is a transition between the original campus to the south, and future development to the north. The primary goals of the masterplan and site design were to develop an identifiable "center" for the college and to strengthen and extend existing campus circulation and spatial patterns.

The first phase of the 164,650 gross square feet project is divided into two buildings—offices and laboratories—and organized around a courtyard which acts as the public "center" or heart of the new college. This courtyard opens on the west to an extension of the Commons Mall, the primary pedestrian connection to the current center of the campus. The east end of the court is open to allow for Phase II expansion. The formal, symbolic entrances to the college are located on a north/south axis that extends through the complex and aligns with an existing tree-lined boulevard to the north. The primary or "front" entrance is located at the termination of this boulevard and forms a pedestrian connection from the campus perimeter through the open air lobby of the office building to the courtyard. The south entrance, on the same axis, occurs at the second level of the laboratory building and provides an open air connection through the building from an existing landscaped campus courtyard.

The project takes advantage of the moderate regional climate by opening the circulation and the public spaces as much as possible to the courtyard and to the campus. Exterior circulation balconies are used at the laboratory building, and terraces with shade structures are provided at the second level of the laboratory building, adjacent to the Commons Mall, and at the third level of the office building. A pedestrian arcade extends the length of the office building along the courtyard, and a cable-supported shade structure covers the open bridge connecting the offices and the laboratories.

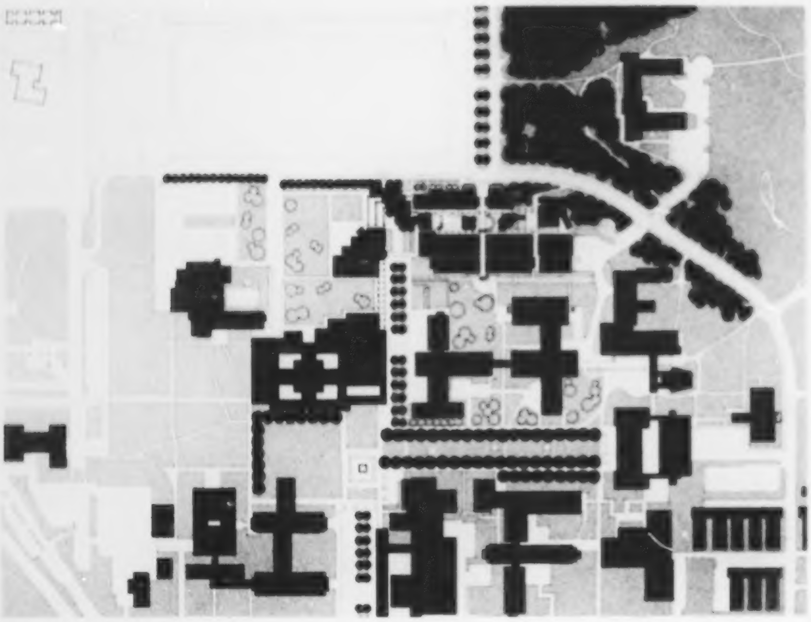
Building Organization

Phase I houses the laboratories, classrooms, offices, and administrative spaces of the Departments of Electrical Engineering, Computer Science, and Chemical and Environmental Engineering. The laboratory building is designed as open "loft" space on a modular planning grid to maximize the long-term adaptability of the laboratories. The ground floor accommodates the high-bay space required for robotics and manufacturing technologies research. The second level of the building is designed to accommodate computer laboratories and a specialized visualization and imaging laboratory. The third level houses chemical, biochemical, and microbiological laboratories.

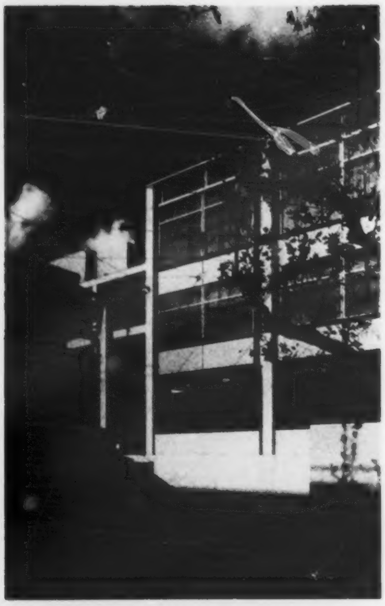
The office building accommodates the faculty offices and administrative spaces of the individual departments and the college. Seminar and meeting rooms are clustered on the first and second levels around a two-story interior display lobby. A general assignment classroom is provided at the ground level adjacent to the Commons Mall.

The building structure is cast-in-place concrete, exposed both inside and out. Exterior walls are clad in brick, in the same color and pattern used as the primary material of the Riverside campus. Aluminum panels are used as infill, and as cladding for mechanical penthouses and shade structures.

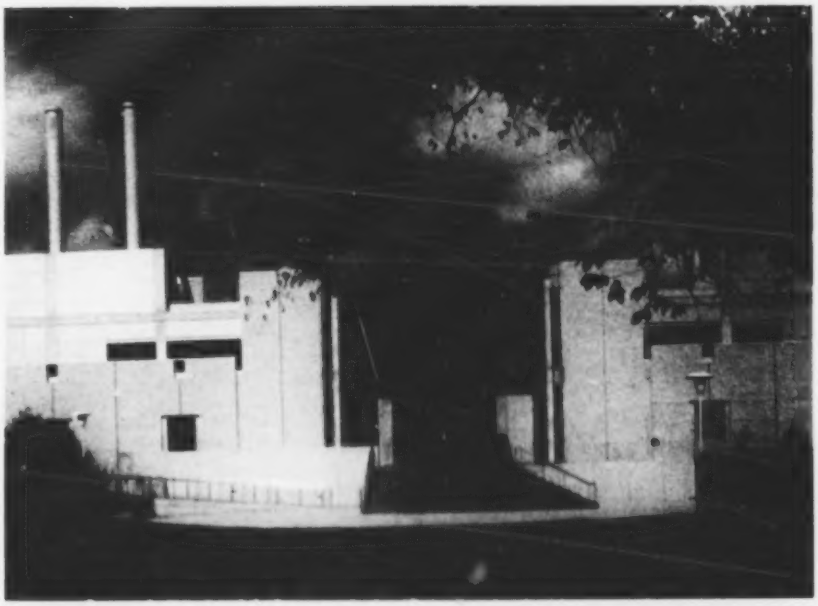
Predominate site materials of brick and concrete are used as an extension of the existing campus. Old growth trees existing on the site were boxed before construction and incorporated into the project at completion.



Campus plan



A pedestrian arcade extends the length of the office building and the bridge connects it to the laboratories.



The south entrance faces the existing campus and provides an open air connection to the engineering courtyard.

The American campus possesses qualities and functions different from those of any other type of architecture or built environment. One of its most important qualities is a peculiar state of equilibrium between change and continuity. As a community, it is like a city—complex and inevitably subject to growth and change—and it therefore cannot be viewed as a static architectural monument. But it is not exactly a city; it requires a special kind of physical coherence and continuity. The planners of recent decades who advocated treating the campus like any urban entity...ignored the special nature of the college and university. As institutions, they have purposes and ideals.... The campus serves the institution not only by satisfying physical needs, but by expressing and reinforcing these ideals or goals.

The result is that uniquely American place, the campus. As a kind of city in microcosm, it has been shaped by the desire to create an ideal community, and has often been a vehicle for expressing the utopian social vision of the American imagination. Above all, the campus reveals the power that a physical environment can possess as the embodiment of an institution's character.

—Paul Venable Turner, The American Campus.

Conclusion. In the process of planning either new programs or new spaces, connections should be recognized and created—among departments and disciplines, between campus buildings old and new. Considerations should be given to the architectural and intellectual connections that foster community. The programs, the spaces, and the structures themselves will not create community. Communities are based on a sense of shared purpose and bound together by a common vision. The end result of all your planning will be new spaces and structures to house programs for the natural science community on your campus. Whether these will actually *work* will depend on the degree to which they reflect the ideas of the many and diverse communities on your campus, as well as the identity and mission of the institution.

It is important also to recognize the communities that surround and shape the external environment for the institution. Representatives of the local community should be informed as your planning proceeds.

Never lose sight of the physical expression of community that is your campus and its best, strongest, and most "characteristic" characteristics. These are what make you what you are; they are what should be preserved and extended in your present planning. Take care to relate science buildings to the overall humanity of the campus—do not create a "science and industry" complex surrounded by pavement and parking. If a new building must be located at the periphery of the campus, as some must, bring the campus to the building.

The opportunity to make a bricks and mortar contribution to an institution may come but once in a lifetime; do not waste it. In your planning, press for a structure that contributes to the strength and clarity of your campus. This can be done if you take care about how and where it is placed, how people experience it, the materials and design motifs that are used, and the proportions and rhythms that give it life. Good buildings are ones that fit into and serve the community in tangible and intangible ways. A campus can have integrity and unity in much the same way that a curriculum can. That should be your goal.

CHAPTER III: LEADERSHIP AND COMMUNITY

Introduction. Moving from idea to physical reality in the process of planning new structures for science is a long, complicated, complex undertaking, one that involves the collaborative involvement and leadership of many members of your community.

Science facilities, even small renovations, are expensive and have to be planned within the context of overall campus and curricular needs. They must be tied to an institutional vision that incorporates the long-term goals and strengths of the college or university, and must be balanced against other needs of the institution.

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Your building will reflect the community that brought it to life; it will then nurture and sustain the community that works within its spaces.

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The process of reaching a campus consensus on planning new spaces in itself can create an ongoing campus community that is sympathetic with, and supportive of, a strong science program. It is this process that makes the planning of new spaces a defining moment in the life of an institution.

Leadership. The challenge to those with leadership roles in the planning process, administrators, trustees, and faculty alike, is to create a climate in which such a community can flourish. Your building will reflect the community that brought it to life; it will then nurture and sustain the community that works within its spaces.

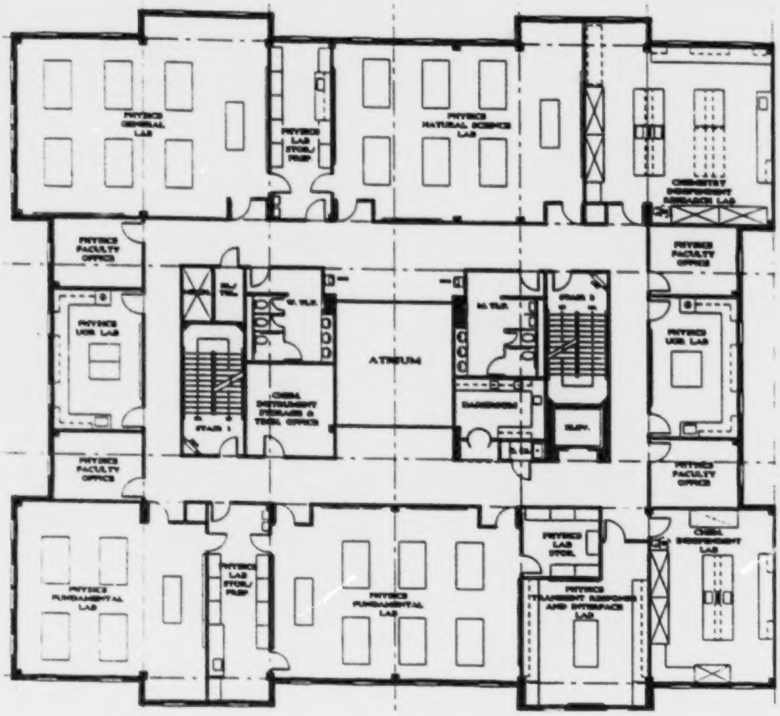
There are different leadership and management roles that come into play in your planning. Each of these involves responsibilities that must be fulfilled if the project is to proceed as planned. How they are assumed and assigned, however, will differ from campus to campus based on local culture and policies, the level of expertise available on your campus, and the scope of your project.

Presidents and other senior administrators will have a significant role in the discussions about mission, academic plan, and campus that brought you to this point in considering new structures for science on your campus. At some institutions, the president will be actively involved during the entire process: as the program is developed, design professionals selected, and other milestones are reached. On other campuses, a designated senior administrator or a faculty member who becomes project shepherd will move into the primary leadership role as the project proceeds.

> ...*I*f universities [and colleges] are first of all associations of human beings, diverse and variously organized, they nevertheless have significant things in common. All are basically concerned with the advancement of learning. All seek to carry on their proper work in an atmosphere of freedom: freedom to pursue the truth wherever it leads, and to talk about it. All are optimistic enterprises, presupposing that our lot on earth may be improved, albeit slowly, bit by bit. They share, besides, many of the attributes of the human creature. Thus, they are sites of both reason and emotion. They are complex, changeable, but also resistant to change. At their best, they are laudable; at their worst, disappointing; most of the time, both of these at once. Such is [its] human nature.
>
> So girded, the university as a human institution can be confident not only of its past but of its present and future, ready to stand up for its aims and basic commitments, both to make its voice heard in the land.
>
> *—Robert Goheen. The Human Nature of the University.*

CRITICAL COMMUNICATIONS: A MEMO TO THE FACULTY

The Hendrix College Story



To every question about planning science facilities there is an answer. And to every answer there is a *"yes-but"* response. At Hendrix College we entered into planning gradually, and after a few fits and starts found our stride. The architects are now at work. Here is how we gave them direction, despite an endless supply of "yes-buts" from faculty in the early stages of the process.

As we began, we had a relatively new president at Hendrix who was extremely supportive. She, and the chief development officer, insisted on realistic planning. The project team, chaired by the senior member of the Chemistry Department, included all the relevant department chairs, the dean, and the staff who would interact with the architects and construction personnel once the building began. As we started planning, we knew a day of reckoning would come, when we would have to "get real" and bring academic planning into line with fund-raising feasibility, and with the institutional strategic plan.

It was obvious to all that the building design should be driven by curricular needs. *Yes-but* "needs" are relative, not only to current offerings, but also to imagination, ambition, and vision. The problems were these: how to get departmental recommendations before the project team on a fair and even footing, and how to have a process that was fair and that served the best interests of the whole science program and of the college overall.

Every early attempt at gathering recommendations from the departments "came a cropper." Responses came in different formats, with different assumptions about the future, reflecting different ways of playing the game of asking for more than is realistic, while expecting a cutback to what was really needed. We needed better information. But how to get it? The project team chair, the natural science area chair, and the dean trod delicately; it was important who asked whom for what, since different persons were "in charge," depending on what had to be asked for. For example, the project team chair could not require a department to conduct a curricular review; the dean could not set a deadline for planning reports.

After sorting things out, the project team, under the leadership of the president, generated a request to faculty that bore fruit:

MEMO:

We need information for our architect and consultant.

One of our most urgent priorities in moving the science facilities planning along is to get the best information we can about our needs to our architect. Various departments have prepared statements of need in response to earlier, in-house requests. We now need to work that material into a form that the architect, and our consultant, can use to prepare a program for the facilities we are planning. Please work as a department to prepare your material in the following format.

1. Aims of the department. *In the context of the department's role in the college, what are the aims, expressed as student outcomes or otherwise, that are the fundamental purposes of the department's work?*

2. Philosophy of education. *What is the theory underlying the department's teaching? For example, how do the concepts of a community of learners, about the personal, participatory nature of the learning experience, and about the contextualization of science resonate within your department?*

3. Pedagogy. *What are the methods to be used to implement the theory? For example, is there to be emphasis on faculty/student contact, a lab-rich environment, investigative or discovery labs, study groups, mentoring, etc.?*

4. Curriculum. *What is the structure of courses, labs, tutorials, seminars, undergraduate research experiences, and so on through which the pedagogy is carried out?*

5. Facilities and spaces. *What physical spaces are required to offer this curriculum? How many offices, classrooms, laboratories, storage and service spaces, and (for all of these) of what sort and size, are needed? What adjacencies should be built in to such spaces?*

This departmental information will be used by the architect and consultant to develop various options for building configurations.

Here are the essential ingredients in effective change-making...:

1. **Visionary leadership.**
2. **Administrative initiatives to authorize and energize change.**
3. **A clear statement of institutional mission.**
4. **An enlarged "sense of the possible" among the institution's members.**
5. **Arrangements for information-dissemination throughout the institution, throughout the process, and for broad participation both in initial change explorations and in formulating final recommendations.**

—Lloyd Averill. Creating a Climate for Change.

This memo gave us pedagogical and curricular specifics for every element in the building designs, and prepared us for discussions with the architect. If we were to cut this lab or that space, we knew exactly what the programmatic consequences would be. Everything was on the table and we did it with our eyes open. Did the memo-process help us to clarify our work? Yes. We had all had enough of *yes-but.*

Three things are necessary to nurture and promote a sense of community: community identity, community interaction, and community involvement. Community identity relates to creating a sense of place. Having a clear sense of place promotes an individual's sense of well-being and level of personal satisfaction. Interaction among members of the community allows for sharing ideas, concerns, and information that permits members to know each other. Community involvement is more than interaction. It is the individual actively caring about what happens in her/his community. It is a loyalty and concern that comes from having a sense of ownership and control over the decisions and direction in which the group is heading.

The challenge . . . is to consider the concept of community, understand it, and promote an environment where it can prosper.

—David Pokorney. Reinventing Community. SCAN. 1994.

Regardless of how institutional culture shapes the leadership structure for your project, it is essential that the president or a designated senior administrator have a strong presence throughout. The president, together with the chief officers for academic and financial affairs, is accountable for the long-term welfare of the institution. Working with trustees and faculty, these senior officers are responsible for anticipating an institutional future, and for securing the internal and external resources to achieve that future. These campus leaders will serve as champions for the project. Senior officers at your institution will make the final decisions about the scope and character of your project, as well as about the timing of construction and fund-raising.

As important as it is to be advocates for the program internally and externally, the president and other senior administrators have the even more critical responsibility to keep your planning focused on a vision of the institutional mission and to ensure that all planners have an "enlarged sense of the possible." This will happen as faculty and staff make benchmarking visits to other campuses and facilities. It should also happen as the campus community comes together to think about "what if" and "why not" in regard to science and mathematics programs on your campus. In the process of thinking about transforming program and space, your campus leaders should see that the right questions are asked at each phase.

Some of the stories in this Handbook suggest ways to keep the project focused on strategic issues. Experiences of other institutions may also be helpful here. One college, in the early stages of planning new facilities, established a science advisory committee of persons with national stature in program reform. These advisors met regularly on campus with faculty and discussed new directions in the disciplines and in pedagogical approaches. Other institutions have had a series of retreats, with or without consultants, to lay out different options for the future as they began thinking about new facilities. There are many other ways to encourage a broad vision, all key to a successful conclusion to your planning process.

The president and senior officers should:

◆ bring the best people to the task from all divisions of the campus, and empower them with the requisite responsibility and resources

◆ see that avenues of communication are kept open and that the discussions are wide-ranging throughout the process

◆ see that decisions are made fairly and firmly

◆ nurture an institutional climate in which ideas flourish

◆ keep the project in harmony with the institutional mission and academic plan.

Once the decision has been made to move ahead with the project, they must also determine the most effective working arrangement with the other key players in the planning process, including faculty who will have a leadership role in the planning.

CREATING SOMETHING NEW

A Leader's Perspective

It is not individuals who determine curriculum or the institutional structure, it is the faculty and administrators as a whole community. When reforms are one-person projects, change is not sustainable.

Here is a central tenet of what constitutes real leadership: getting people to collaborate. Faculty and administrative leaders need to think collectively about linkages between the mission and the practices of the institution. They may be doing this in a time of budgetary crisis, and/or a time of decreasing public support for what we do. For reforms to succeed and be sustained, leaders have to figure out how to build an environment in which faculty are rewarded for working on problems that are educationally significant and of highest concern to the institutions.

Leadership to accomplish this at the local level requires a deep sense and knowledge of the external environment, of current issues in higher education, of disciplinary and faculty culture. It requires the capacity to connect, to make complex linkages between different spheres of action, at many levels in an institution. It requires the ability to communicate across institutions, disciplinary and departmental borders, to speak the language of others in the community.

The challenge to leaders is to build an environment in which ideas can flourish, where risk-taking and the possibility of failure are acceptable, where the structure has the flexibility to accommodate new ideas, and provides regular opportunities for collective action. The challenge to leaders is to capitalize on the diverse strengths that different members of the community bring to the reform effort, understanding how senior and junior faculty each bring a particular perspective to the work of translating ideas into action. The challenge to leaders is to develop a culture that supports the free flow of ideas and the collective efforts of the community.

Our concern as administrators is a special one. We have the role of building communities of people on and off campus committed to improving undergraduate science and mathematics learning. These communities usually gather to work on a particular problem and try to bring about change through a novel idea. On a college campus most members of this community become engaged in reform efforts because of their commitment to the institution and to the students.

The object of the community's work in this process, individually and collectively, is to create a favorable climate for change, so that each step in the process is seen as inevitable—a logical next step to achieve institutional goals. An added benefit of an ongoing communication plan is the capturing of good ideas from unexpected quarters of the community about reforms in science, as well as the planting of seeds campus-wide about the value of hands-on, collaborative teaching and learning. Communities do not happen spontaneously. They are built intentionally and nurtured by leaders who understand how to give power and authority to the members of the community. The challenge ever present is to balance the diversity within the community with the vision that brings together people of good faith to create something new.

Board of Trustees. Boards of trustees (particularly of private institutions) have crucial, but strongly delimited, responsibilities in regard to major facilities projects. These follow from the trustees' general responsibility for the long-term welfare of an institution. For private institutions, trustees also have significant fund-raising responsibilities.

New facilities of any kind become part of the overall physical organization of the institution and thereby affect generations of faculty and students. Projects for new or renovated science facilities cannot be undertaken unless the institution is prepared to garner (and expend) substantial capital funds in addition to expanding its operating budget. Trustees have the final say about how much an institution is prepared to spend on a project.

◆

New facilities of any kind become part of the overall physical organization of the institution and thereby affect generations of faculty and students.

◆

Trustees approve or make final decisions about which architect to hire and about where a new building will be located, what it will look like, and how it will relate to the rest of the campus.

Trustees have the responsibility to:

- make sure a productive collaborative planning process—one that involves all relevant constituencies—is firmly in place from the start
- know when it is necessary to hire, and approve the hiring of, consultants
- select/approve the selection of an architect
- understand the "program" for the project, and the process for estimating the cost
- make sure the project is financially feasible
- coordinate the potential funding possibilities so that they mesh together most effectively, and so that the institution does not set its sights too high or too low
- work with the development professionals on the campus to design a feasible fund-raising plan—and to raise the money that is needed to do the project right
- review the design plans at regular intervals
- pay particular attention to where the building will be located on campus, how it will relate (both aesthetically and logistically) to the rest of the campus, and the long-term implications of the project on maintenance, utility, and other costs
- monitor changes in cost estimates as the building develops. This is particularly important throughout the design process and as construction documents are prepared. Such monitoring should continue throughout the construction process as well.

Trustees, finally, should lead the celebration when the project is completed and make sure that all who worked on and supported the project receive credit for their contributions.

LOOKING AT AN INSTITUTION'S PAST, PRESENT, & FUTURE

A Trustee's Perspective

The primary role of college trustees is to provide stewardship for the college. Stewardship means taking responsibility for a college's or a university's reputation, vision and aspirations, as well as its physical, human, or monetary assets. Besides their obligations to their colleges, trustees also owe some loyalty to the best interests of the community at large, either local, regional, or national. Trustees implement or exercise their hopes, visions, or aspirations for the institution by appointing and working with a president. Together the trustees and the president work to implement an agreed upon philosophy and set goals for the institution; it is the president's responsibility to lead the academic community toward the attainment of those goals. This exercise in combined leadership is never more important or demanding than in the planning of curricular revisions, especially those that require changes or additions to the building inventory of the college or university.

As always, trustees must challenge the institution's leadership to think creatively and courageously. Through an aggressive approach it is possible for a college to make greater rather than smaller strides, but at the same time, the trustees must also expect a sense of reality as future oriented projects are conceptualized and proposed. When trustees encourage faculty to "think big," it should not be interpreted to mean that every one of their wishes can now be achieved. Trustees expect a team of faculty and administrators to probe and question every request and proposal for space in the new facility, and then, when appropriate, to refuse or scale back proposals which exceed the institution's means. On the other hand, trustees can sometimes anticipate, by virtue of their experience, needs that have not been discovered by faculty or administrators. Through the cooperation of trustees, administrators, and faculty, therefore, it is possible to develop a better and more comprehensive plan for the institution.

One does not have to be an expert to recognize the advances unfolding in modern science. The importance for our nation of a citizenry educated with an understanding of science and mathematics is well known. Trustees have an "oversight" duty to ensure that their institution is contributing to the national need for a better educated society in which there is an understanding of the scientific approach and the use of quantitative methods. Trustees should look first to the college community's academic plan to meet these needs and, if the academic community's approach appears to be inadequate, trustees should ask the administration for a more complete approach.

The construction of buildings or the renovation of spaces should never be planned for their own sake, that is, just to have something new, but rather they should be linked with the advancement of academic goals. Buildings should be constructed only when a programmatic plan demonstrates that the new ideas can be implemented only with newly constructed or renovated facilities. Trustees have an important set of responsibilities when presented with proposals for construction, renovation, or additions to buildings on campus. All colleges have limited land resources and a limited capacity to raise capital funds; therefore, trustees must ensure that buildings are not constructed unnecessarily. Once the need for a new science facility has been justified to the board, it is the responsibility of the trustees to support the administration and, in turn, to become advocates for the project so that the required financial resources can be uncovered. (It is convenient that the same logical justification for convincing a governing board can become the statement of purpose and the rationale for selling the project to a philanthropic organization.)

High-quality academic communities yearn for distinctions that will endure. Innovative approaches to the education of tomorrow's youth, permitting them to thrive in a world strongly influenced by science and mathematics, will be joined with pride by trustees as they view the historical role of their college in the community of colleges and universities in this nation.

In the workshops and colloquia on facilities PKAL has hosted since 1992 we have challenged participants to be conscious of the relationship between the success of the collaborating community and the success of the spaces that emerge from their work. Participants comment:

"...we now recognize that a characteristic of community is informed discussion, and that there has to be institutional commitment if the project is to succeed."

"We also recognize that designing a building is a community-builder; we have been impatient, planning too much department by department...."

In the spirit of these comments, we suggest a community that works is one that:

- has a clear understanding of the students of today, and of the future in which they will live and work
- energizes gifted and respected leaders in the faculty and administrative ranks, and gives them the requisite flexibility, responsibility, and resources to effect change
- understands the critical questions to be asked at each stage in the process of reform, and asks them in a context of mutual respect and shared commitments
- takes risks, seeks new collaborators and supporters, develops partnerships that dissolve boundaries within the academy and within the larger community of stakeholders
- broadens the discussion, redefines the problem, and understands the kaleidoscopic nature of efforts to build natural science communities that serve the national interest.

—PKAL Occasional Paper #2, 1994.

Community. As you plan, you will be building community by clarifying institutional goals, thinking toward an enhanced image for the sciences and mathematics on your campus. Make certain that these new spaces and structures make a statement that for your institution these disciplines are truly liberal arts. The building of community is critical, because you have to be sensitive to the possible disruption to the sense of community that such a visible and large investment of scarce institutional resources could cause.

In the process of planning, connections should be recognized and created, between departments and disciplines, between campus buildings old and new, connections that nurture community.

If faculty, administrators, and trustees have wrestled with articulating an institutional vision that shapes and connects to what actually happens in classroom and lab, a vision that articulates how the various elements of the campus community connect (physically and intellectually), there should be a common understanding of and commitment to strong programs in science and mathematics as institutional priorities. In the process of planning, connections should be recognized and created, between departments and disciplines, between campus buildings old and new, connections that nurture community.

The characteristics of community—a predisposition to share ideas, to challenge precepts, and to revel in exploring unfamiliar territory—relate directly to the endeavor of collaborative planning. How can this be? Think about how a true community exhibits the willingness, even the drive, to discuss matters of the moment informally with colleagues in the lounge, or to explore issues in formal, regular sessions with peers. Community is the spirited enactment of the conviction that ideas are important, and that they gain life when people bring different perspectives to their consideration. Communities embrace a common vision, yet allow—even promote—difficult dialogues. This is the challenge to leaders, within the faculty and the administration, as your planning proceeds.

Conclusion. Planning takes a long time. All involved must make a personal commitment to take the time to wrestle, individually and collectively, with questions about educational goals, about the nature of community, and be ready and willing to bring particular experiences and expertise to the larger campus-wide discussions on these issues.

We end Part One of this Handbook with a chronology of one institution's journey toward that end.

> **A community must have a common aim, and the common aim of the educational community is the truth. It is not necessary that the members of the community agree with one another. It is necessary that they communicate with one another, for the basis of community is communication.**
>
> *—Robert Hutchins.*

WHAT IT TAKES: A STEP-BY-STEP CHRONOLOGY

The Illinois Wesleyan University Story

At Illinois Wesleyan University it took fifteen years between the first call for a new science facility and the day it opened. If the average working life of a science facility is thirty years, with a renovation after fifteen, then the duration of the planning stage is equal to the half-life of the entire building! If you use the planning time as well as the science faculty and administration of Illinois Wesleyan did, then the facility will more exactly meet your specific needs and goals, and your time will be well spent. Here is a chronology of the planning by the Division of Natural Science, which includes the departments of biology, chemistry, computer science, mathematics, physics, and psychology.

The old facility served a significant part of the student body; roughly one-fifth, or 400 of the student body of 1,800 were science majors. Faculty pushed for a new facility because the old science building lacked space for offices, for teaching labs, and for research labs. Among other deficiencies in the mechanical and support facilities of the building, the university had major environmental safety concerns with the building's improperly designed ventilation system. In 1985, a planning task force proposed that a new science building be opened by the mid-1990's.

The problems in the old building were so serious that the college decided to replace rather than renovate the science center. To do this well, the faculty first looked at what in the current building/program

1964	Sherff Hall of Science, 34,000 gross square feet, opened and occupied with approximately 80 science majors and 13 faculty in four fields of study.
1980	Problems with existing space detailed to president and dean in the context of developing a five-year strategic plan (1980-85).
1982	Campus Master Plan developed for the next 15-20 years. Three site options for new science building were included.
1985	"Task Force 1990," developing a Strategic Plan for the 1985-90 period, identified a new science building as a need to be met by "the mid-1990's."
1988 February	Document titled "A new science building for Illinois Wesleyan University" prepared from individual department assessments and reports. (30 pp.)
1988 May	Final report of another strategic planning committee (convened by new president) again identified a new science building as a high priority.
1988 August	At the request of the Development Office, a background paper "Science Education at Illinois Wesleyan: The Prospect for Excellence" prepared and circulated. (19 pp.)
1989 Fall	Leadership gift Case Statement prepared (33 pp.). Local architect commissioned to develop presentation materials. Initial construction costs projected at $19.6 million.
1991 February	Three IWU representatives, including IWU's president and the vice president of the board of trustees, attended PKAL's First National Colloquium in Washington: "What Works: Building Natural Science Communities."
1991 Summer	Architect selection process completed.
1992 Spring	Architectural program and schematic design developed. Cost estimate projected at $22 million.
1992 May	Public phase of campaign announced; goal of $58 million to be committed by Fall 1995.
1992 Summer	Design development. Cost estimated at $24 million.
1993 Winter	Bids and contract awards made. Final contract cost slightly under $25 million.
1993 May	Groundbreaking.
1995 Fall	Occupancy.

was working and should therefore be preserved. They concluded that their most valuable asset was the collegiality and cross-disciplinary communication which resulted from being "under one roof." This unity had the unintended effect of having students "hanging-out" in the building, and helping each other's research both intellectually and practically.

To extend this lucky "under-one-roof" quality further, (from something we happened to inherit from the old design,) into today's interdisciplinary work, everyone agreed that the general principles for the building's planning would be: common spaces and classrooms should foster *interactive, interdisciplinary,* and *collaborative* learning. From these general goals, faculty decided on several specific ways to implement them:

- a single facility to meet all instructional needs of the six departments
- use of tables rather than tablet-arm chairs in all classrooms
- an emphasis on reassignable space; multifunctional and flexible, with attention to safety
- support for faculty-student collaborative research, i.e., no reserved space for instructors in labs
- the value of a space's "function" for all disciplines would take precedence over its "form" for *one single* discipline
- efficiencies through provision of opportunities for programs to share facilities (primarily in teaching labs and support facilities)
- research space for computer science and mathematics roughly on par with that available to students in the lab sciences.

Several testimonials of participants in planning discussions show how special these conversations were for the direction of Illinois Wesleyan, and how the university met its special needs.

> "The most controversial decision we made was putting the faculty offices into a separate zone, and not integrating them with the research and teaching labs. Many faculty would have preferred a tighter cluster of offices, research labs, and teaching labs. Although this pattern has many advantages, we felt it isolated faculty from one another, even within their own departments. Furthermore, while designing a "community of science" is good, and something we wanted to do, there is not one single way to do it. We made the community that we thought would be best for our faculty: all departments in the same area, with each department's offices all in a cluster, and sharing a common lounge or interaction area."

> "We developed a nice way of exchanging ideas between leadership and faculty. It was a kind of 'top-down and then back again' operation. Leadership would 'seed' ideas to the faculty, and the faculty would send them back up with comments and arguments on what was really workable and/or really would assist teaching. Concerns of the faculty often lead to refinements, sometimes to revision or wholesale rejection of ideas presented to them. This kept discussions alive, people involved, and everyone from burning out."

◆

Furthermore, while designing a "community of science" is good, and something we wanted to do, there is not one single way to do it.

◆

Was our time spent working out the particulars and preparing the facility worth it? Yes. While we wish we could have had our building ten years earlier, it would not have been as fine-tuned, or as near to perfect for our needs. Had we rushed we would not have gotten what we have now and we would have had to suffer some generic notion of what a science facility is for the next thirty years or so. Our building is definitively ours; we paid with careful planning to make it exactly what we want.

Illinois Wesleyan University Center for Natural Sciences Learning and Research

Bloomington, Illinois

Architect of Record:	Hastings & Chivetta St. Louis, MO
Design Architect:	ADP/Fluor & Daniel Tucson, AZ
Lab Planner:	Earl Walls Associates San Diego, CA
Net to Gross Ratio:	57%
Size:	132,000 GSF
Net Square Feet:	
Teaching Labs	23,216
Research Labs	9,496
Support Facilities	11,320
Classrooms/Lecture	11,980
Faculty Offices	6,500
Building Support	1,820
Shell Space	10,500
Total	74,832
Construction Cost:	$20,565,000
Construction Cost/SF:	$156
Completion Date:	August 1995

Illinois Wesleyan University planned to build a new facility to house the university's science programs. The administration expressed the need for a facility of high architectural quality to enhance campus ambiance. As a major investment to the university, the building will be functional, accessible, environmentally acceptable, and secure with deinstitutionalized spaces conducive to formal and informal interaction. The building's systems will be physically adaptable to changes in technology and curriculum.

Exterior of building.

Campus Context

The site planning of the structure facilitates the major building functions and enhances the existing surroundings while becoming a contemporary backdrop to the traditional character of the university's Main Quadrangle. The Center for Natural Sciences Learning and Research architecture is designed to blend with the campus and respond to the regional context and human scale of the university.

Multifunctional & Flexible Space

With 132,000 gross square feet, (74,800 net assignable square feet) the new building's main function is that of an instructional facility with laboratory support. Courses are planned for biology, chemistry, physics, geology, psychology, mathematics, and computer science. The building contains lecture halls, classrooms, teaching laboratories, commons areas, administrative offices, and support space. Research laboratories totaling 9,500 square feet are available for students and faculty. High traffic zones are segregated from private areas.

Functional Organization

The building is organized by function rather than by academic department. The functional zones of the building are: teaching and research labs; faculty offices; classrooms and computer labs; and lecture/auditoria. These four functional areas intersect at a building commons.

- **Interactive**
- **Interdisciplinary**
- **Collaborative**
  were the guiding principles for planning the building

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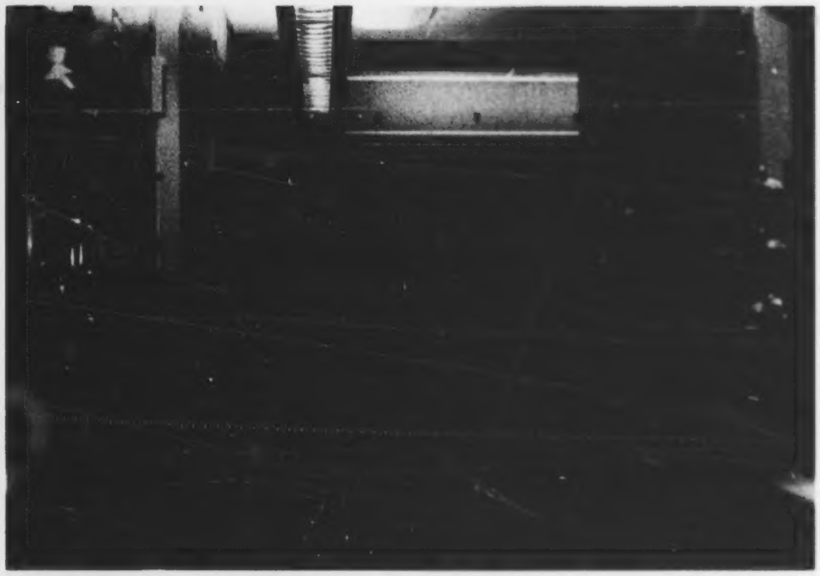
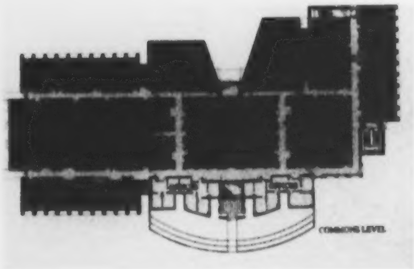
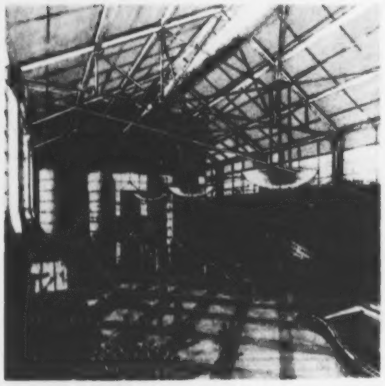


Organic chemistry teaching lab.



Lower level floor plan.

General biology teaching lab.



Commons perspective.

General chemistry teaching lab.

Innovative Teaching

The building is completely networked for data and communications, with cable trays incorporated for ease of maintenance, connectivity, and flexibility. Vertical distribution is via fiber optic cable with horizontal copper runs. Lab/classrooms for computer science and mathematics are equipped with Sun workstations. Additional computer labs for modeling and simulations are provided adjacent to wet lab areas in biology, chemistry, and physics. The two lecture/auditoria are equipped with state-of-the-art multimedia systems, and all classrooms are furnished with tables, rather than tablet-arm chairs, for an easy transition to wireless networking of students' notebook computers.

Project Objectives:

- **Single instructional facility**
- **Multifunctional, flexible areas**
- **Attention to safety**
- **Faculty-student research**
- **Functional building organization**
- **Interactive spaces**
- **Nontraditional research spaces**
- **Flexible classroom spaces**

The building includes a commons, located under a skylit space, for students, faculty, and the campus community to meet and share in the discussions of different sciences.

PART TWO

PEOPLE AND PROCESS

Chapter IV
The Planners

Chapter V
Phases of Planning

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PART TWO

> There is one timeless way of building
> is thousands of years old, and the same
> as it has always been. The great tradition
> buildings of the past, the villages and te
> and temples in which man feels at home
> always been made by people who were ve
> close to the center of this way. It is not p
> to make great buildings, or great towns, b
> tiful places, places where you feel yoursel
> places where you feel alive, except by foll
> ing this way.
>
> There is a definable sequence of activitie
> which are at the heart of all acts of buildin
> and it is possible to specify, precisely, unde
> what conditions these activities will generat
> a building which is alive. All this can be m
> so explicit that anyone can do it.
>
> *Christopher Alexander, The*
> *Timeless Way of Building*

We here describe how to identify and assemble the people to be involved in the planning process, and outline the steps through which designs move from the programming stage to the point of construction documents.

Planning a new facility, even a single classroom or laboratory, is a defining moment in the life of an institution. Not because you will solve the problem of too little space for too many faculty and students or the problem of inadequate hoods or leaking roofs, but because the process becomes a communal effort. In coming together to wrestle with the why and the how of new structures and spaces for undergraduate programs in science, mathematics, and engineering, your community will both shape and be shaped by debates and discussions about matters of broad and mutual concern.

Each of your project committees, under the leadership of the project shepherd and the project manager, will face several challenges as you proceed. You will be challenged to think about the future of programs for the natural science community on your campus from the broadest possible perspective. You also may be challenged to think through whether to undertake renovations (minor or major) or build anew, and to consider how spaces and structures being planned can serve your institution in the most cost-effective and efficient manner for many years.

In planning new spaces for undergraduate science and mathematics programs, individuals and committees representing the campus community work closely with design professionals to determine how much space should be provided, how many different types of spaces should be provided, and how many faculty and students are to be accommodated in each space. Thus, as members of the planning team, your design professionals need to gain a perspective on how you want your courses to be taught, your students to learn, and your faculty kept active as scholars and teachers. Communication is the key to a successful project, and the final challenge is to be open to sharing new ideas, willing to debate and negotiate and to learn a common language about program and space.

CHAPTER IV: THE PLANNERS

Introduction.

The development of a science facility involves many different individuals and groups whose contributions must be solicited and used effectively throughout the many years of planning. Project leaders must be mindful that all with a stake in the project have opportunity to shape the vision for the new spaces and structure.

This chapter defines specific responsibilities for each of the players in the planning process, individually and collectively. The spheres of influence and responsibilities of persons in leadership roles overlap. This requires consultation and communication from the point of selecting the project shepherd, establishing the project committees, and engaging persons with the requisite technical expertise in planning and programming, design, and construction.

Campus cultures and structures for planning differ, and such differences will determine the timing and sequence of bringing the people together for your project. Usually, however, the first step will be to identify key individuals, such as *project shepherd* and one *project manager.* The project shepherd is usually a faculty member from one of the departments involved in the project, someone with a keen sense of the academic program to be housed in the new spaces. The project manager is often a member of the facilities office, someone with technical expertise about planning and construction. The project shepherd may have had a leadership role in earlier discussions about curriculum and campus. Or perhaps she or he may be selected in conjunction with establishing the project committees, once the decision has been made to proceed.

Depending on the scope and complexity of the project and institutional cultures, campuses will differ as to when they bring in individuals and firms with particular expertise (campus planning, programming, costing, lab design, construction management). Although the chronology of planning will differ campus to campus, there are general guidelines for identifying and selecting the right people to be involved in the process. There are also well-tested approaches to the functioning of the project leadership based on a commitment to collaboration, communication, and consensus.

Project Shepherd.

Central to a successful project is the project shepherd, who is indispensable as leader and spokesperson for the project. Preferably a faculty member, this is the person who keeps the project moving ahead and facilitates communication between and among all committees and individuals involved in the planning. The key charge to the project shepherd is to know precisely what is to happen in each of the spaces within the new facility. She or he has the ultimate responsibility to ensure that the spaces work as faculty intended and that they truly improve learning for the natural science community on your campus.

The characteristics of the best organizations tend to bring out the best in people. Note that all of the characteristics deal with human relationships. No mention is made of technology, economic considerations, or the product. The entire focus is on human qualities—how and why people work well together....in conclusion, all people are at their best when they are an essential member of an organization that challenges the human spirit, that inspires personal growth and development, that gets things done and that symbolizes and stands for only the highest standards of ethical and moral conduct. That is what quality of work life is all about.

—*William Ouchi, Making Theory Z Work.*

THE PROJECT SHEPHERD: COMPROMISES AND CHALLENGES

The Keck Joint Science Center [Claremont Colleges] Story

Building a new facility—from concept to completion—is a big job. It is important for one person to be in charge, someone who can be the contact person for faculty and administrators, architects and contractors. She or he will have to attend the weekly or biweekly meetings during the period of planning and construction and deal with multiple challenges and compromises that need to be addressed. The person needs to be diplomatic, able to deal with and arbitrate the potential areas of conflict, and well aware of the various needs and operating styles of colleagues. Here are some of the compromises and challenges we faced in bringing our dream for the Keck Joint Science Center to reality—and some advice.

Beginning the planning is easy; it involves little conflict. Just ask faculty—individually and as a group —what they want! Faculty are very good at planning research and laboratory areas and even offices and support spaces. However, challenges soon arise. Faculty are less adept at knowing how to plan for and incorporate spaces to make the building livable for students. They are also not experienced in thinking ahead, anticipating facility needs for new or emerging programs. Faculty need to be encouraged to think about how to plan for flexibility (read: placement of utilities). They need to think about changing research priorities when retirements occur. If the current ecologist, scheduled to retire in five years, wants a flowing artificial stream in his lab, can it be easily (cheaply) removed if his successor does not want it?

Another challenge is to arrive at the proper square footage. If you say you have $15 million for the project and need 75,000 square feet, architects will demonstrate that you can "purchase" a $11.25 million building ($3.75 million for site preparation, architects fees, building permits, contingency funds, and equipment) that will give you a building with 75,000 square feet at $150/square foot. Given that buildings have 60 percent usable space and 40 percent other (hallways, bathrooms, mechanical rooms, HVAC, etc.), you now have 45,000 square feet of usable space—and a problem.

Of course, the cheapest building (read: most efficient) is a rectangle with no frills. Many college science buildings are like this; they serve faculty fairly well, with plenty of labs and research areas. However, your building is for students! Will it be a place where students enjoy working at 10 P.M.? Fight hard to save the "friendliness" of the building, i.e., places where students gather. Our four-hour lab sessions are much more tolerable with a place nearby for a snack break. Indeed, one of our prime considerations was clustering faculty offices around social areas where students would feel welcome. Getting the shape right meant thinking carefully about how we wanted people to interact, not simply about what fit best into the available space.

Compromises were necessary at many stages. When we were faced with the need to downsize the building, one of the big "economies" was to get rid of the 200-seat lecture hall. Although it would have been good to have one in the new building, on our three campuses there were already several lecture halls of that size that were not being used during the hours we would need them. The administration agreed to remodel one of these (in an adjacent building) adding a portable lab bench, thereby saving us 3,000 square feet. That compromise was relatively easy to achieve.

Some compromises dealt with *where* to put *what*. Chemistry is cheapest on the top floor, due to the cost of fume hood vents. Did that work? Most of the mechanical rooms, shops, and storage worked best on the lowest level. Would that be the most efficient use of space? Did we want to divide departments by functional levels? (Did we want any offices anywhere near the anatomy labs?)

Other compromises were faced as we began to think about labs. We found that the exterior design, when divided into interior spaces, required squarer labs than desired, giving extra space on one floor and not enough on another. Some of our laboratories migrated to different floors during this period, and several areas changed size from the original program.

Through much compromise, we were able to accommodate all faculty desires and meet our goal of maintaining the friendliness of the building. We did lose some space for expansion, but persuaded the administration to excavate more area in the basement and leave it as unfinished (and cheap) shell space for the future.

A significant set of challenges came as we learned the joy of dealing with building codes and city ordinances. For science structures, there are requirements and codes for almost everything, and we had to consider them carefully as we began to move into the final planning stages. You may wish to have office doors open to a social area; the fire codes may demand closed doors. Work closely with your project manager, architect, and on-campus facilities officers to learn about codes, which will probably address the following:

- number of windows relative to requirements for heating and insulation
- number of doors per laboratory and their location within the lab
- number of bathrooms
- corridor and aisle widths
- number and widths of stairways and elevators
- animal rooms
- access and signs for the disabled
- fire safety rules for fire walls and doors
- storage of volatile chemicals and toxic waste.

The final challenge comes at the point when you must get faculty to work with you in reviewing the construction documents. This is the stage that determines, finally, what you will have to live with in the future. Some faculty may assume that they can tell you, or the project manager or architect, what they want and it will automatically appear. But you cannot assume anything; if you want under-the-counter microscope cabinets to open away from the knee hole openings in the workbench—say so. Then determine that this is the case. Once construction starts, although they will be less frequent, the regular meetings will continue. Issues will come up that are important to faculty, ranging from office furniture selection, to how to key the building, and perhaps even whether you can live with a different kind of dishwasher (because the floor drain is in the wrong place).

Compromises were necessary, but we didn't compromise on making this a building in which students feel welcome. It works for them and it works for us.

My advice to someone following in my shoes? Expect surprises, expect challenges you could not have expected, and expect to feel ignorant of and scandalously treated by the planning process. On the other hand, know that you can use the planning process, too. You *must* use it and the planning documents as tools for finding out what your working space for the foreseeable future is going to be like. Remember, when you look at the plans, that there is a reason for everything, and the plans are the best tool to use to find out what the reasons are. Make the planning documents your friend.

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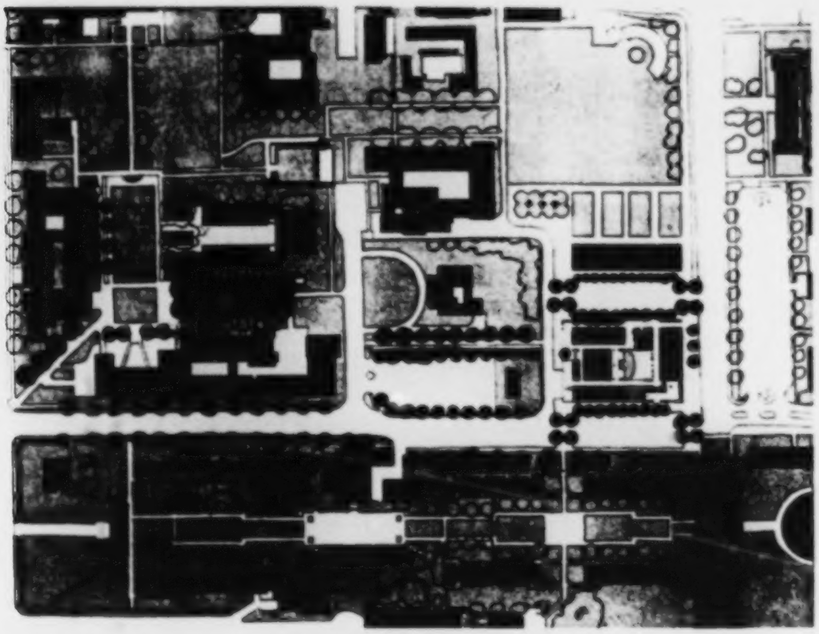
Claremont McKenna, Scripps and Pitzer Colleges The W.M. Keck Foundation Joint Science Center

Claremont, California

Architect:	Anshen + Allen Architects Los Angeles, CA
Size:	81,193 GSF
Construction Cost:	$12,130,234
Net Square Feet	
Laboratories	23,699
Lab Support	10,151
Offices	3,758
Animal Colony	1,307
Classrooms	2,437
Shell Space	5,500
Total	46,852
Completion Date:	November 1991



The science center is located at the confluence of three colleges. Scripps to the west, Pitzer to the east and Claremont McKenna to the south.

Background

The planning for the new W.M. Keck Science Center involved the faculty of the Joint Science Department which serves Claremont McKenna, Pitzer and Scripps Colleges and also the administrations of these three colleges. Key issues were the site, scale, and placement of the new facility which needed to make a positive statement about the increased importance of science in each college's academic program. The site selected is at the intersection of the three campuses, convenient and visible to each. A significant architectural challenge was to avoid a "back" door. Thus creating a building with four attractive facades accessible from all directions was our charge.

Design Issues

An important design criterion was the need to create space for interaction and informal conversation among both faculty and students. The placement of faculty and administrative offices, with laboratories and the corridors between them, maximizes faculty and student contact. The central, open courtyard between the two wings also serves to encourage informal interaction. Open corridors on the east wing, the courtyard and the landscaped light wells (possible in the benign climate of Southern California) create vistas across and within the facility. Students and faculty are readily visible as they move from one part of the building to another.

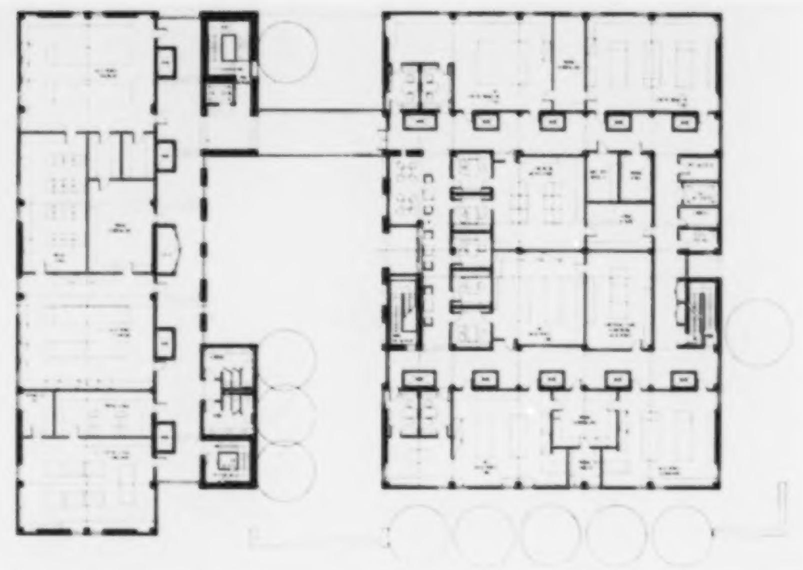
The dramatic use of large windows on all floors, including the basement through creative use of light wells, landscaping and interior color scheme all promote a "user-friendly," attractive environment. This teaching facility is designed to attract students to science and reflects the faculty's commitment to make science exciting rather than forbidding.

Building Organization

The building is organized as a three-level structure in two wings focused around a central courtyard. In order to reduce height and massing, the building contains a basement level with two levels above grade.

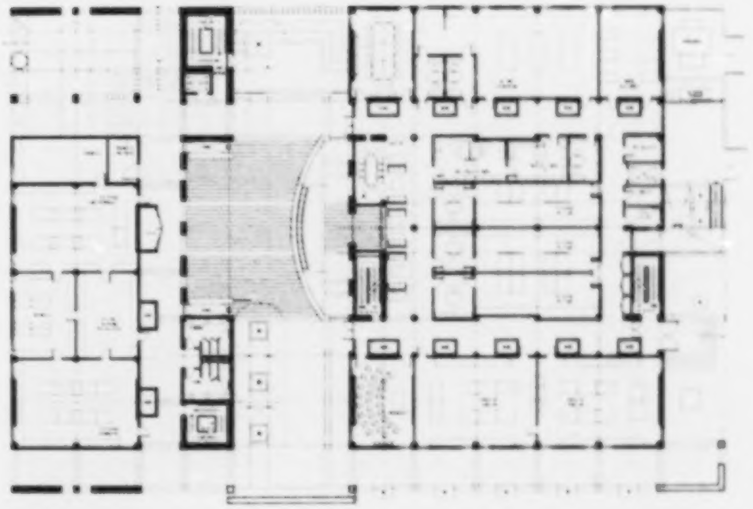
The concept of a two-wing planning concept was in response to the differing laboratory sizes and functional requirements. The east wing contains larger scale teaching laboratories served by exterior circulation balconies. The west wing contains predominately smaller-scale teaching and research laboratories accessed by an interior corridor. Located adjacent to research laboratories and circulation patterns, faculty offices with interactive spaces are located on each level facing the central courtyard. The basement level contains labs, building support services, an animal colony, and a tiered 75-student classroom, accessible to a lower level exterior courtyard. The first and second levels contain both advanced and introductory teaching labs, research lab support spaces, and faculty offices.

Flexibility and modularity are key concerns and to that end the laboratories are organized in open, structure-free spaces. Mechanical, electrical, telephone and data services are organized in adjacent circulation corridors. This strategy allows for the laboratories to change over time with less cost to the building engineering infrastructure. In addition, the placement of services in vertical shafts along the corridors creates entry niches to the labs which have become display areas for artwork and student projects.



The second floor plan shows the exterior balcony circulation of the east wing, the bridge connection to the west wing and the interior corridor of the west wing.

Rooftop mechanical equipment sits below clay tile roof structures which link the science center to its campus context. In the foreground is the east wing.



The first floor plan shows the central entrance courtyard with east and west science wings.

We pay a heavy price for our fear of failure. It is a powerful obstacle to growth. It assures the progressive narrowing of the personality and prevents exploration and experimentation. There is no learning without some difficulty and fumbling. If you want to keep on learning, you must keep on risking failure—all your life. It's as simple as that. When Max Planck was awarded the Nobel Prize he said: "Looking back...over the long and labyrinthine path which finally led to the discovery [of the quantum theory], I am vividly reminded of Goethe's saying that men will always be making mistakes as long as they are striving after something."

—*John Gardner, Self-Renewal.*

The project shepherd must be:

- a good communicator, responsible for seeking a consensus among the faculty
- knowledgeable both about the nature of the disciplines of science and mathematics included in the project and about teaching methodologies, sensitive to the limits of compromise, and when and how changes would limit the program
- responsible for maintaining adherence to the facility program
- effective in setting priorities
- knowledgeable about blueprints, responsible for reviewing room/floor layouts as necessary and suggesting modifications as necessary
- a good salesperson, responsible for negotiating compromises and for making the case about the significance of the project
- committed to the institutional vision, responsible for upholding the values of the departments and the institution.

The project shepherd, together with the project manager when she or he is identified, sets meeting dates and agendas and facilitates the implementation of committee recommendations. The project shepherd also works closely with the development office to ensure a reasonable, long-range fund-raising plan. The shepherd may coordinate the faculty role in promoting the project to prospective donors.

The project shepherd must be committed to the project and have the trust of the faculty. In representing the viewpoints, needs, and educational goals of faculty colleagues, she or he must be open to debate and disagreement and understand how to challenge individuals and departments to ask questions in a context of mutual respect and shared commitments. Ideally, the project shepherd should have released time at critical stages in the planning and construction process.

Project Manager.

The project manager must understand the entire process of planning and renovation from a technical point of view, and have the skills to keep the project on schedule and within budget. The project manager may be from your facilities office, an external consultant, or a staff member of the architectural firm. Some institutions elect to contract with a project management, construction management, or program management firm, once this phase of the project is reached.

Since the project manager's role is more of implementing the plans of the institution, she or he is most often selected prior to or immediately after the selection of the architect. The charge to the project manager is to oversee the project scope, budget, and schedule, and to assure that all these are met within the parameters as defined by the program and established by the institution in making the decision to undertake the project. Depending on the relationship with contractors, the project manager may or may not manage the construction process.

In regard to project scope, the project manager maintains:

- ◆ adherence to the facility program
- ◆ design intent and integrity, and project quality
- ◆ parameters of the project (compliance with current codes and compliance with established institutional standards and systems)
- ◆ commitment and coherence to the institutional vision and campus master plan.

In regard to project budget, she or he monitors:

- ◆ adherence to the budget as set by the governing board or senior administration
- ◆ requirements for cost estimates at each phase of the project
- ◆ assessment of the feasibility of alternatives relative to the facility program, and other aspects of scope, budget, or schedule
- ◆ initiation and progress of consultant fees and contracts.

In regard to project schedule, the project manager assures timely completion of all phases of the project.

Committees.

Three primary project committees will be needed.

◆ **Building Users Committee.** This is the committee that "starts the ball rolling" after the commitment has been made to move ahead with the project. It includes representatives of the faculty and staff who will be housed in or otherwise affected by the project. Students can be valuable members of this committee also.

◆ **Project Team.** This is the operational committee, the group that makes the day-to-day decisions that keep the project on target and consistent with the authorizing charge from the administration in regard to scope, budget, etc.

◆ **Executive Committee.** This is the senior-level committee that ensures that the project is in line with the educational mission and financial resources of the institution, and that mechanisms are in place to secure funds for the project in a timely fashion.

Depending on your structure for managing the project, these committees will be under the leadership of the project shepherd and/or the project manager. As the project proceeds, **subcommittees** will be assigned to undertake specific tasks. Ultimately, it is the board of trustees or regents that has the final say about the project.

Building Users Committee. The most successful projects follow from a commitment by individual building users to be engaged in the process, and from the development of procedures and structures to facilitate that engagement. Faculty and staff with a stake in the outcome of the planning must be enfranchised at every stage as the planning proceeds. Be certain to take seriously the ideas and suggestions of all faculty members. *Do not plan a new building that is obsolete when it opens because it only incorporates what the senior faculty have lived without!*

As the project proceeds, the project shepherd will represent the faculty at the table and "report back" to her or his colleagues about issues considered and decisions made and to be made. This input from faculty generates a sense of ownership in the project and makes it easier to move from programming through design development to construction.

The planning process will benefit if representatives of the support and custodial staff who serve the entire building are included. These individuals can provide a different perspective on building layout, usage, and design which may not be apparent to faculty whose ideas may be influenced by familiarity with the functions and layout of a single department. Staff who serve all departments will know how visitors relate to the building and how students unfamiliar with a particular department make sense of the traffic patterns and spaces. They will also know how communication among building occupants is affected by its layout. Custodial staff have experience with and can provide valuable input on the effects of local usage habits and climate upon maintenance of different types of surface finishes, furnishings, and accessories.

Project Team. On the project team are representatives from appropriate departments and administrative offices, and from the design, engineering, and management firms engaged for the project. This is the core group that keeps the project moving; the members must be optimistic, objective, committed—and have a sense of humor. They have the authority to make decisions about the design and construction of the spaces, and the responsibility to bring the community into agreement on alternate design possibilities. They take the lead in resolving issues and problems that will inevitably arise at various stages in the process.

Under the leadership of the project shepherd and/or project manager, this team keeps communication open between other leadership groups and individual faculty and administrators with relevant areas of interest and experience. To be most effective, the project team members need to integrate their decision-making process with that of the campus community as a whole. For example, team members will have to justify to the project's executive committee that the needs (as defined in the program, cost, and designs) have been determined conscientiously; they will also have to assure the building users that their ideas matter.

◆

The project team is the core group that keeps the project moving; the members must be optimistic, objective, committed—and have a sense of humor.

◆

The underlying charge to the project team is that the planning process and the resulting project serve the mission of the institution for the long-term. To accomplish this, they must see that community is built through the active participation of users.

The project team will be called upon to make generic decisions about issues such as population, group size, modules, offices, flexibility, and interactive space. Once the project planning is underway, they will also be called upon to address more specific issues, such as shell space, special areas, safety, image, HVAC systems, etc. There will be hard decisions to make; politics will enter into the decision-making arena. Dealing with regulations and codes, focusing on the possible use of new technologies and facing potential departmental reorganizations can be unsettling to those involved for the first time with such issues.

The construction manager and/or the general contractor usually joins the project team at a later date, as the architectural design is completed and construction documents are prepared and signed. Other planners, designers, engineers, and management consultants may move in and out of the project as necessary. This might include, for example, subcontractors and/or cost-estimators.

Including a secretarial support person on the committee provides an experienced contact person who can schedule meetings and prepare materials for them, collect information from committee members, communicate with design professionals and construction personnel, and manage and maintain the many files and records which will result from the committee's work and form an important archival resource for the institution.

The development officer who will have primary responsibility for developing the "case statement" used to seek gifts and grants in support of the project should be an *ad hoc* member of the project team, and participate in most of the initial discussions between the project shepherd and other faculty. This person will have the responsibility to translate the dreams and vision of the faculty into rhetoric that is persuasive in securing the financial support of foundations and individual donors for the project.

Executive Committee. The executive committee for the project ensures that the project is in line with the educational mission and goals of the institution, that the monetary resources are in place, and that fund-raising efforts are in line with the planning and construction schedule. The executive committee serves as the link to the board of trustees in regard to this project.

The key administrators on the executive committee are the president, vice presidents for academic affairs, finance, and development, or their representatives. Each of these senior administrators needs to understand and be supportive of the curricular goals of the faculty as developed in the context of the planning process. The administrative leader, the project shepherd, and representatives of the project team will also serve on the executive committee.

HOW USERS SHAPED THE SCIENCE COMPLEX

University of Oregon

Planning the new science complex at the University of Oregon involved intense faculty involvement through a core users committee, which had the charge to think through what would be needed in spaces through the year 2000, and to develop a conceptual model for organizing that space in ways that accommodated the program. It had primary responsibility for drafting the program that defined the project for prospective design professionals, and for putting together proposals to secure necessary funds for the project. The members worked closely with the campus planning committee, a standing committee of the university that brings the overall campus perspective to each facilities project. The "direct users" of the new facility worked with the core users committee and the architects to determine how much new space would be allocated to various teaching and research activities within departments and institutes, and decided on the principles to be used in distributing this space among new and existing buildings.

The building users and the architects began with two challenges: first, to figure out how to provide physical connections between departments and the interdisciplinary research institutes at the university. (In addition to traditional departments, at the U of O we have a number of institutions that cut across departmental lines: molecular biology, chemical physics, materials science, theoretical sciences, and neuroscience. These are not freestanding, but are tightly integrated with the departments.)

The second challenge was to use the opportunity afforded by this capital project to return to the historic campus planning principles established by Christopher Alexander (*The Timeless Way of Building*) that had shaped our physical plan in earlier years.

As might be imagined, at the beginning, reaching agreement about priorities was not easy: everyone was crowded; everyone anticipated new positions; everyone wanted more space. Consequently, the initial requests from task forces asked for more than twice as much space than hoped-for funding could support. The situation became even more complicated as we began to consider that funding would be considerably reduced. Without the sense of ownership that was emerging, it would have been more difficult to reconcile the different space needs within the anticipated budget.

There were many meetings over a two-month period to discuss and justify the individual requests, to eliminate overlapping requests, to compare requests to national norms for comparable programs, and to seek more efficient uses of space. At the end we were pleasantly surprised as the users had come to an agreement not only on priorities, but also on a conceptual plan for organizing new spaces and connecting them to existing spaces.

From the first it was recognized that the ideal arrangement would allow a faculty member to have an office and laboratory (and research assistants) located in a manner that would facilitate both interaction at the level of the department and the institute. Planning for such integration was particularly difficult because we were dealing with existing buildings as well as new buildings. To guide the thinking the users committee developed the conceptual model of "horizontal and vertical" integration; the departments would be located in individual buildings (vertical integration), and the institutes would be located on the same floor of each building that houses departmental faculty members in that institute (horizontal integration).

As we developed this concept, we could see the many benefits for the community. Not only would it provide the integration between departments and institutes that we were seeking, it also helped reduce space needed: seminar and classrooms, administrative offices and support areas could be shared. Everyone began to work toward the common goal of this horizontal and vertical integration.

Now that the buildings are occupied, it is interesting to see how well this concept works in practice, as illustrated by the spectacular atrium which connects the new physics building and the existing chemistry building. Most of the hallways of the physics building are open to the atrium and the two buildings function as one. The aim of the planning committees, to encourage both planned and spontaneous interactions, is achieved by the integration of the buildings. The atrium now, in truth, serves as an agora for science on our campus. We even have a coffee shop!

Other important examples of integration can be seen throughout the buildings. Stairway "connectors" attract people for a variety of reasons: the quality of the space, and the fact that many administrative offices, seminar rooms, and other shared spaces open directly onto these connectors.

Involving the users so early, and so substantively, in the planning process helped in two important ways. First, if we had not involved users so thoroughly, we probably would have arrived at less suitable designs, and with facilities that serve less well. Most important, decisions about the allocation and organization of space would not have been so well accepted. The success of the building users in developing conceptual models addressed critical needs of the community and led to a very high degree of "ownership" in the project.

One key to our success was the series of participatory "workshops" over a four-month period which involved architects, representatives of the building users, and other appropriate faculty and administrators. In these workshops, everyone presented ideas, listened closely to the ideas of others, and began to merge the hopes and dreams of individuals and departments.

An important part of the workshops dealt with site considerations, a particularly sensitive issue on the campus. It was our intent that this project would be more in tune with historical plans for the campus, plans that had been ignored as new buildings were constructed in recent years. Specifically, we went back to explore how the work of Christopher Alexander, in his ideas about campus patterns at the U of O could be applied to this project. We walked around the campus, noting views and paths, existing buildings and potential locations for new structures. One important pattern for Alexander (recognizing our often damp and dreary climate) was courtyards facing south. We determined that these could be achieved, and further, that our new buildings could be positioned to preserve and enhance important views and shield ones less attractive.

The workshop dealing with departmental issues began with broad discussions about ways to organize buildings for teaching and learning in the sciences, considering both the character and spirit of the places, as well as how they are used. Small groups then broke into groups and made collages using colored paper to code laboratories, office spaces, and service areas. What became very clear in this workshop was that for most scientists on the campus, social relationships were key to the process of doing science—at the undergraduate as well as the research level.

This was fun and everyone entered with enthusiasm into the process. We all took to heart some of the key patterns stressed by Alexander, in particular the "social stair." This is a pattern that suggests the use of stairs to encourage social and academic interaction. Every department eventually integrated a carefully located social stair into their planning.

The workshops resulted in some sophisticated studies in which many creative ideas were presented. The ideas explored at these workshops became the touchstones for further planning and design, with specific ideas taking on a life bigger than any of us expected. While the process was time consuming, one that greatly complicated the lives of project leaders, it was worth it.

The strength of the planning process at the University of Oregon was that it captured the energies and imaginations of many people, and built on rich institutional traditions in regard to faculty self-governance and to integrating art and architecture across the campus. Moreover, the patterns and processes of planning stemming from the work and writings of Christopher Alexander that were institutional traditions, and the design impulses and ways of working descendent from the insights and forms championed by Charles W. Moore were also interwoven in essential ways into the planning process.

One of the most precious things about good places is that they result from the energies of many people; they are not lonely feats of imagination. The science complex at the University of Oregon is uncommonly ingenious in the intermingling of new buildings with existing structures, replete with elements of art and crafts not normally present in contemporary construction; it intricately yet variously conceives as a place where work (scientific work, no less) is not set apart from personality. (Adapted with permission from *Places*.)

On most campuses, the senior academic officer will have been actively involved in the initial discussions about mission and academic plan. The dean has the continuing (and daily) responsibility to keep the larger and long-term perspective on the academic program. It may well fall to the dean occasionally to remind everyone of how the institutional mission shapes project goals.

In the event of identified cost overruns, the executive committee will be called upon to support or secure approval for additional funding or to request modifications in design to reduce the project's scope. Thus, the vice president for finance needs to be actively involved, bringing an understanding of the ways and means of the institution to the deliberations. She or he will have to build the financial bridge between the scope of the project and institutional financial capacity. Science facilities are expensive to build and to operate; ways to cut costs and save money will be one of the main priorities for the chief financial officer.

Special Subcommittees. Subcommittees are necessary to tackle specific issues, and to capitalize on local experience and expertise. Subcommittees may be appointed to focus on the physical plant (hazardous waste and chemical storage, cold rooms, animal facilities, or landscaping). Other subcommittees may give attention to curricular matters, such as use of technology, shared spaces, and interdisciplinary programs. Subcommittees might also address broader institutional needs, such as long-range planning or fund-raising.

In addition, there will be special subcommittees set up by the project manager and/or the construction manager to manage the process of construction; these will include the design professionals, engineers, and contractors involved with the project. The project manager and/or project shepherd, depending on the managerial policies set for the project, will attend these meetings and serve as institutional representative and as a conduit of information back to the leadership committees.

Every project has a context because the committee is working in a larger environment. College committees often become isolated entities and act as if the larger community has no relevance for their particular task. The project shepherd must take care to communicate regularly, both internally and externally.

◆ Keep careful records of meetings and of the planning progress. These should document decisions reached (when and by whom), and main points of the issues being discussed by various committees or subcommittees. Copies should be sent to selected faculty and administrators, either routinely or as appropriate for issues discussed. An open copy of the public project file should be kept in an easily available place.

◆ Keep nonscience faculty informed, both formally through committee structures, and informally during faculty coffees, etc. A scheduled lunch conversation with an involved faculty member may help generate the widespread support needed for a successful project. It will help if the departments to be served by the new facility can articulate "why" and "what" to their colleagues, from the broader institutional perspective.

GUIDELINES FOR COLLABORATION

The Dean's Perspective

It is important to remember that when committees are established for a specific task, individual relationships often change. People who have known each other for years are asked to think together in a different way, and to become a collaborating community that addresses such differences. It is vital that the early life of the group be built around openness and trust, with procedures, time frames, work plans, and schedules established democratically.

Ownership connects to trust. Everyone needs to feel that her or his individuality is acknowledged, even as the group joins together for the larger goal. Those in the leadership roles, particularly the project shepherd, must probe for disagreement and diversity of perspective. This persistent examination of difference builds trust in a common enterprise, and enfranchises all involved. Your aim should be to keep the planning process as far as possible from partisan and parochial skirmishes and encounters.

Some guidelines:

◆ Make sure it is clearly understood at the very outset what the "givens" are, what is not subject to adjustment.

◆ Don't let people settle too early into a conception of the project. Before stating solutions or developing basic designs, have people state their own needs and hear those of others.

◆ Make people talk through conflicts honestly and clearly. Don't try to keep people from fighting; worry rather about insuring they fight fair. Don't let conflicts smolder unexpressed, even if they are based in cleavages of long-standing. Don't let anyone's voice be muted, and don't let anyone seize the high ground—whether or not that putative high ground is of "extraordinary importance" or "prudent economy."

◆ Seek consensus, not decisions by narrow majorities. Try not to let anyone luxuriate in the role of the permanent minority. Finding consensus may involve finding a common language. Help people talk across the boundaries of expertise, particularly between academics and construction people. Restate each side's view in ordinary words; you will be corrected—try again.

◆ Put off decisions that aren't ready to be made. Move things along, but do not hurry. However, respect the schedules of architects, engineers, and construction firms.

- Prepare materials about the project (new curricular plans, current faculty/student research activity, etc.) for presentation to alumni, trustees, and other constituencies. Work closely with the institutional public relations office throughout the process to tell the story of the project.
- Work toward building the awareness of the contribution that a strong undergraduate program in science and mathematics will make to the larger community.

Design Professionals. Selecting the architect, lab designer, and other professionals who will be involved in the design and construction of your science and mathematics facilities will be a critical responsibility for the project committees. Facilities such as these are technologically and programmatically complex; they typically require years from first designs to occupancy, as well as larger capital expenditures and higher operational costs than almost any other building on your campus. Thus, the selection of the design professional should be undertaken systematically and thoughtfully. Facilities that are not well designed may be more costly over the long term; they may compromise the effectiveness of the learning environment and/or create unsafe conditions for your students and faculty for years to come.

Since science facilities are quite complex structures governed by a plethora of codes and regulations, it is centrally important for the design team to have the requisite experience and expertise to develop the overall design *and* to get the details right. A few architectural firms have sufficient expertise to do the complete design of all spaces, including laboratories with in-house staff. Another approach is to involve a laboratory design specialist as a consultant. The laboratory design firm can either work as a consultant to the client directly or be hired as a consultant to the architect of record. In either case, the lab design firm will do the design of the laboratory spaces, while working closely with the architectural firm. The lab designers will also supply design criteria to the engineers, who will be designing the mechanical systems. Since science buildings involve very complicated engineering systems, it is very important to involve an engineering firm with substantial experience with such facilities.

It is critical to identify design professionals with specific experience and expertise in regard to your project. Look at an architect's other work; investigate and evaluate the breadth of a candidate's technical abilities as you proceed through the various stages in the selection process. Equally important, you should also seek evidence of how the candidates would work with your community, and how sympathetic they are to the special requirements of projects like yours. The goal is to identify professionals with whom you can be engaged in a productive and collegial collaboration during what will be a lengthy period of planning and construction.

Depending on the scope and complexity of your project, the selection procedures will be more or less

formal. The process described here requires the participation of the administrative leaders, project shepherd, members of the project team, persons in the finance and in the facilities offices, and perhaps even representatives from the board of trustees. You might form a more formal "selection subcommittee" for this task. A single individual should oversee the selection process meetings and be the point of contact for candidates. This will probably be the project shepherd or project manager.

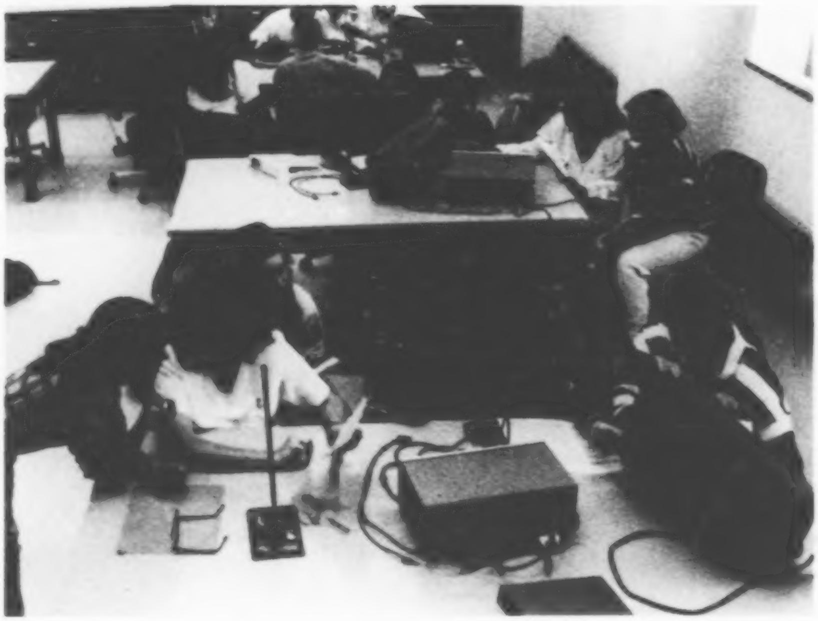
Timing the Selection. When design professionals are selected will differ from project to project, institution to institution. Sometimes an architect is selected before final decisions have been made about the project's site or program. Most architects are trained in site planning and some have experience in developing detailed programs for science facilities. For some colleges and universities, the sooner an architect is hired, the sooner the architect will learn about the project and be able to provide better services to the institution.

Many factors determine when you should begin the process of selecting your design professionals, including the complexity of the project or the inexperience of your campus in planning a new science facility. Instead of moving directly to engaging an architect, some institutions first work with a campus planner or programmer to assist in completing a preliminary description of the overall project program and site. (The selection process for these experts is similar to that described on the following pages.)

> **If we are interested in the management of creativity and change, we must consider the role that strategy plays. A strategy is a plan to reach our goals cleverly. While it is sometimes possible to reach goals in a muddling and fatalistic way, there are advantages in thinking strategically, in using forethought, and in combining tactics as skillfully as possible.**
>
> **Strategic thinking and planning are intimately connected with creativity and change. First of all, strategic thinking itself is a creative act. For most of us, strategic thinking is not automatic. It is a divergence from business as usual and not easy, since it causes us to confront the large uncertainties associated with the future. Most of us are aware that we should be thinking strategically about our personal lives. Those of us who do tend to accomplish our goals more readily.**
>
> *—James L. Adams, The Care & Feeding of Ideas.*

The Long List. The first step in the selection process is to identify candidates for the "long list." In the course of your visits to other campuses and discussions with colleagues, names of architects and firms will probably have surfaced, but another place to look is your regional chapter of the American Institute of Architects. You should aim to include anywhere from seven to fifteen different architectural firms on the long list. Too short a list may not capture the best potential candidates, and too long a list may risk a cumbersome review process and discourage potential candidates from responding.

The Request for Qualifications. Once you have composed the long list with the project team at your college, prepare a "Request for Qualifications" (RFQ), and convey it to the firms on the list. The purpose of the RFQ is to secure enough information to choose firms for the short list.



So that the firms on the long list can be responsive to your particular needs and planning goals, in the RFQ you should provide:

- a general description of the anticipated project, including size and location
- a general description of the academic program, design goals, and project participants
- a description of the stage of development (e.g., at the beginning of planning, initial programming completed, ready to start design)
- established project requirements such as preliminary budget and schedule
- background information on existing buildings, including the campus master plan, if available.

Although most campuses are made up of a variety of architectural styles, some colleges and universities prefer to have buildings designed within a particular style. If your campus has special architectural traditions, you should make them clear in the RFQ. If a firm does not have experience with a certain style, it may choose not to be considered for your project. In the RFQ you will ask each firm for:

- information about the history and size of the firm
- a list of key individuals including résumés, references, and awards
- descriptions of similar projects (in size and scope) recently completed.

In the RFQ you should inform the architects about the criteria you will use in the selection process, concerns or questions you will raise in the interview, and how the architects will be selected for the short list. At this stage, firms on the long list will have no formal interview, but some architects may wish to visit your campus to develop their response. This should not be discouraged, although a site visit is more appropriate for firms who have made it to your short list. Two to three weeks is an appropriate time to allow for a response to the RFQ.

The Short List. After receiving and reviewing the qualifications submitted in response to your RFQ, you should select the best four to six candidates and ask them to respond to a "Request for Proposal" (RFP). Here you will be seeking more detailed and comprehensive information to make an informed final decision.

The Request for Proposal asks:

- How will you approach our project?
- What are the most important issues in our project?
- How do you establish priorities and make decisions?
- Who would be assigned to this project on a day-to-day basis, provide overall management during the construction process, etc.?
- How does your firm typically establish a fee for the project?
- How do you manage schedule and costs during design and construction?
- Who would you recommend as engineers and consultants?
- What similar projects have you recently completed, and who are the contact persons on those projects?
- What are the qualifications of persons to be assigned to the project? (Detailed résumés and references should be requested for these individuals.)

You may include a draft of an "Owner/Architect Agreement" with the RFP, either one prepared locally or a copy of the "Standard Form of Agreement between Owner and Architect" from the American Institute of Architects (AIA form B141). Firms should be asked to indicate what modifications they would propose to such agreements.

As a part of the RFP, you may also ask for a formal fee proposal, with the mutual understanding that this only represents a guideline that you will use in reviewing proposals from the different firms. It is difficult, if not impossible, for an architect to determine accurately the services required at such an early stage, thus it is not easy to project a commensurate fee. Architects should be able, however, to describe how their fees are established and their standard scope of service.

Include all names on the short list with the RFP, so each firm can decide whether to prepare a complete proposal. The preparation of a proposal in response to the RFP requires a substantial effort, often including a visit to the site. Typically three to four weeks are allowed for a response.

It may be useful to make visits to other projects completed by firms on the short list. This should be done by the time of the interview, so that information can be used as you interview the candidates. It is critical to check references thoroughly, contacting several past clients. (As with your earlier visits

> **The architect is a sort of theatrical producer, the man who plans the settings for our lives. Innumerable circumstances are dependent on the way he arranges this setting for us. When his intentions succeed, he is like the perfect host who provides every comfort for his guests so that living with him is a happy experience. But his producer job is difficult for several reasons. First of all, the actors are quite ordinary people. He must be aware of their natural way of acting; otherwise the whole thing will be a fiasco. That which might be quite right and natural in one cultural environment can easily be wrong in another.**
>
> **...the architect's work is intended to live on into a distant future. He sets the stage for a long, slow-moving performance which must be adaptable enough to accommodate unforeseen improvisations. His building should preferably be ahead of its time when planned so that it will be in keeping with the times as long as it stands.**
>
> **...the architect, too, works with living things—with human beings....If they cannot thrive in his house its apparent beauty will be of no avail....Indeed, one of the proofs of good architecture is that it is being utilized as the architect had planned.**
>
> —*Steen Eiler Rasmussen, Experiencing Architecture.*

to other campuses, be certain to have a formal set of questions to ask about the collaboration with the architectural firm and about what works and does not work in the resulting spaces.)

The Interview. Once the selection committee has received proposals from firms on the short list, rank them by criteria similar to that used in reviewing the responses to your RFQ. Then you should invite any or all of the candidates on the short list for an interview.

When preparing to interview the different design firms, be sure you are going to interview the actual "project team" from the firm. Sometimes the project is "sold" by one team and the work produced by another. The value in hiring a firm with experience building your kind of facility is to have the benefit of that experience at every meeting, including the first interview. Clearly, therefore, you will want to make your hiring decision based on the people you hire, not simply a firm's prestigious name. (If it is your practice to work with a local architect, be aware that other qualifications, such as knowledge or experience, may override the attractiveness of familiarity.)

Prior to the interview, if they have not done so, architects should make a visit to the site and meet the faculty and administrators involved in the project. This is to ensure that the upcoming interview will be a productive exchange of information and ideas.

In preparing to interview the firms on the short list, compile a list of issues that all candidates will be asked to address, based on the criteria established earlier. Careful attention to consistent criteria throughout the process helps members of the selection committee manage the selection interviews in a coherent manner. Representatives of your board of trustees may participate in this stage, depending on the scope of the project and your institutional practices and policies.

If possible, all interviews should be scheduled for the same day or consecutive days to keep the selection process focused. Besides presenting their work on similar projects during these interviews, the architects should describe how they will address your project's program, develop the design, manage schedule and costs, administer the construction contract, identify the project site, and describe their standard method of collaborating with the client.

Interviews should take about two hours, divided equally between the presentation by the architect, time for questions, and a thorough exchange of ideas. The individuals from the firm who would be assigned to the project should make the presentation, as personalities and human chemistry are important in what will be a long and close collaboration. How people work together will play a significant role in determining much of the ultimate success of the planning process and final project.

Once you have made your decision, remember to notify all firms that were interviewed about the decision: the one selected and those that were not.

Occasionally, ratification by the trustees is required for the formal letter of intent to be executed.

This letter from the college will formalize the working relationship until a formal agreement can be signed.

Design Competition. For major projects, you may consider holding a "design competition" and invite a small number of firms who have responded to the RFQ to participate. In this instance, architects typically are provided a predetermined fee to offset costs incurred in preparing for the competition. In a design competition, architects actually submit initial plans of work they would do for you, which they do not do during the standard interview process outlined earlier.

Through a design competition, you can gain a better understanding of how different architects would approach your project, specifically what siting, massing, arrangement of program elements, and architectural style they would favor and propose.

Architects invited to participate in the design competition should be given all available information, including the preliminary program of spaces developed by the science faculty, the proposed construction budget, siting preferences, zoning codes, and any other restrictions and/or information that might affect the project.

As the selection committee reviews submissions to the design competition, you should understand that these represent only preliminary proposals. Developing thoughtful architectural designs for facilities as complex as those for undergraduate science and mathematics requires an enormous amount of time and effort, typically twelve to fourteen months, during which there is extensive interaction with institutional representatives. The time and interaction generally associated with developing a project for a design competition is generally much less.

Criteria established at the beginning of the process will be used as you evaluate entries to the design competition and come to a final decision.

The Contractor. The architect typically assists the college or university in the selection of the contractor. If the contractor is to be selected on a competitive basis, the architect can assist in the development of a list of prequalified contractors. The architect can produce a prequalification questionnaire that is typically sent to a "long list" of contractors. Following the review of the information provided by the contractors, a "short list" is developed of those deemed to be qualified for the project. (Note that public colleges and universities often are not able to limit the list of bidders.) The contractors that are invited to submit bids for the project are provided bidding documents. The architect can assist the owner in distributing these documents and in receiving and analyzing the received bids. During the review period, questions asked by the bidding contractors are answered by the architect and the engineer through addenda. The owner and architect typically work together to arrive at a decision about the contractor.

HOW TO GET A GOOD BUILDING: PROCESS AND IDEAS

The Architect's Perspective

About the rebuilding of the Houses of Parliament, Winston Churchill said something akin to "We shape our buildings. Thereafter, our buildings shape us." This is a particularly important statement because it says that socially and functionally, our behavior is affected by the shape of the places we inhabit. For this reason, and because you rarely get a second chance, at least not in the same building, get it right the first time.

What works is understanding the importance of process, the importance of being a good client and being a good architect, the importance of good ideas. For the client there is a "Bill of Rights and Obligations." For the architect, there is an explanation of what constitutes good behavior.

For the client, I have fashioned a "Client's Bill of Rights and Obligations." Not exactly crafted by a founding father, but it's not bad. With rights come obligations in a responsible world, or in a world where you want to make certain that your rights are retained. These are obligations to self and society and they pertain to individuals and institutions alike.

You have the right:

- to participate, to act in your own behalf. There can be no surrogates. With this right comes the obligation to ask intelligent questions.
- to be informed and to understand. An architect must be able to explain a project, functionally, socially, and aesthetically, in clear and comprehensible language. With this right comes the obligation to educate and organize yourself about your needs and preferences, hiring advisory help if necessary.
- to like and to dislike, especially the latter. (Clients have a right to be pleased with what they pay for.) With this right comes the obligation to be articulate about what you want and why you want it. The more an architect understands a client's preferences, the easier it is to design and serve well.
- to get good value in service and in building. There should not be wasted resources. With this right comes the obligation to pay fairly and reasonably, for the service and for the building. (Nothing comes for nothing...but in today's world if everyone is not vigilant, you can easily get "plenty-of-nothing" for lots of something.)
- to architects with good ideas. They should be sympathetic to your aims and objectives; with this right comes the obligation to decide intelligently. The richest experiences and best results grow out of an intelligent cooperative dialogue between professional and client.

From the architect's perspective, it is critical to understand and manage the complex, multicentered, multi-interested, often divergent, sometimes contradictory, always interesting client that is an academic institution.

In every such circumstance users are concerned with preferences, accommodation, and their own space needs. There is an inherent tension between the administration and the building users. Administrators are concerned about cost in the short- and long-term, about maintenance and campus-wide space needs. The tension here is between the inherently conservative and the perpetually demanding. The architect's (the project's) greatest success will come from building consensus through positive participation.

Before design can begin, productively or intelligently, a design professional must develop an understanding about the institution in three critical areas:

- history, which tells us about the culture of the client and the place, and about appropriate antecedent examples, both disciplinary and architectural, to examine
- context, which tells us about the character of the community, the region, and the physical locale of the project

- site, which tells us, through analysis, about the topography, vegetation, access and egress, orientation to sun and to views. From these, we can develop ideas that are appropriate to the physical opportunities and limitations created by the site.

From analyzing and understanding these areas, the architects can participate intelligently in developing the program, and/or designs.

Such understanding serves as a foundation from which the search for appropriate themes and the freedom to design freely can proceed. The key is finding the intersection between what is known and what is possible. In so doing, architect and client can work together to create a marriage of their experience, knowledge, and aspirations.

The responsibilities of the architects are to:

- bring the best team to the project and have the key players participate throughout
- provide well-coordinated efforts in design, management, and architectural technology
- help clients to organize themselves
- keep clients apprised of developments and decisions of consequence
- manage and control project information so nothing gets lost
- manage the budget, from beginning to end.

The best architects listen to their clients carefully. They listen, respond and listen again, to all involved in a project. The seed of a great solution is often planted in an unexpected place. Every architectural project has a soul. By listening, and by asking the right questions of the users, that soul can be discovered. It is the essence, the key to a successful result.

Beyond or before architectural ideas, an architect brings social ideas to the planning process, based on understanding the institutional client; ideas that help a client to understand itself. Then architecture can begin.

A satisfied architect means architectural and aesthetic goals have been reached. A satisfied client means an architect has heard the client's voice, acknowledged and responded to her or his needs, wishes, desires, hopes, and dreams.

Conclusion. In most cases, the time span for planning will be many years. All members of the project committees must recognize this, and not become disenchanted during the seemingly endless process. It will help if, from the very first, you establish protocols for communication. Advance agendas and accurate minutes, regular communications to the community about how the planning is proceeding are essential. Equally important, particularly in working with your architect, is that there is clear understanding who is responsible for each specific task, and that you have an agreed-upon schedule for making decisions and for signing-off as decisions are made. It is important to watch out for land mines, for they will appear; it is also important to understand how your community comes together in the planning process. Encourage candor and criticism; learn to trust your instincts. Finally, set clear goals for your planning, goals that are both visionary and realistic.

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CHAPTER V: PHASES OF PLANNING

Introduction.

When you have made it to this stage in your planning, with an institutional commitment to move ahead, you should have arrived at a clear, communal understanding of the future shape of your curriculum and your campus. Development and budget officers will have made some positive preliminary determinations about the financial feasibility of the project, from the beginning of the design phases through to constructions and during the lifetime of the building. A sense of reality now takes hold and the hard work begins. This will be a time of intense, focused, and sometimes messy discussions about specific spaces and about the relationships between spaces. Your earlier explorations into curricular possibilities, your benchmarking visits to other institutions, and your individual and collective thinking about the future will serve you in good stead. As you begin defining the program and continue to monitor the development of designs—until and through construction, keep in mind that the goal of your planning is to build a hospitable environment for the natural science community on your campus, one that will serve your students and faculty today and for the thirty-year life expectancy of the facility.

The Facility Program.

The facility *program* is a translation of vision, curriculum, and pedagogy into facility needs. Defining the facility program is the mechanism by which consensus is reached by your campus community.

The facility program includes:

- **executive summary,** describing overall project goals, needs, schedule, and budget
- **space summary,** listing types, sizes, and quantities of spaces
- **building planning criteria,** listing applicable codes and guidelines and describing strategies for accommodating flexibility, circulation, accessibility, security, etc.
- **room design criteria,** including tentative worksheets listing room-by-room requirements for hoods, environmental conditions, chemical usage and storage, plumbing, electrical and telecommunication services
- **room diagrams,** illustrating layouts for laboratory benches, hoods, sinks, and equipment
- **adjacency diagrams,** indicating functional relationships within and between departments.

Larger institutions typically have someone in the physical plant, facilities, or planning organize the process. Often, because of the scale and complexity of a science facility and the lack of experience of college personnel with the planning and design of a major science facility, the college or university secures the assistance of an architect, planner, or programming consultant with experience in planning science facilities in the facility programming phase.

The information drawn together in the facility program indicates whether or not a feasibility study is needed (see page 82); it is also used by a cost consultant (most often contracted for by the architectural firm) to provide a relatively

> **Most modern institutes of education, despite the apparent neutrality of the materials from which they are constructed...carry within themselves implicit ideological assumptions which are literally structured into the architecture itself. The categorization of knowledge into arts and sciences is reproduced in the faculty system which houses different disciplines in different buildings, and most colleges maintain the traditional divisions by devoting a separate floor to each subject. Moreover, the hierarchical relationship between teach and taught is inscribed in the very layout of the lecture theater where the seating arrangements—benches rising in tiers before a raised lecture—dictate the flow of information and serve to "naturalize" professorial authority. Thus, a whole range of decisions about what is and what is not possible within education have been made, however unconsciously, before the content of individual courses is even decided.**
>
> —*Dick Hebdige, Subculture: The Meaning of Style.*

Design and building are group activities. Many people and firms come together to do a project; they may not have worked together before and they may not work together again. They collaborate to produce a complex and usually unique result on a specific site. As the project unfolds, hundreds of individual design decisions and commitments are made. Needs and conditions change, and work is modified. A strong and healthy relationship between owner and architect is essential to keep the project on track.

—*American Institute of Architects, You and Your Architect, 1987.*

accurate projection of construction costs. When the detailed facility program includes preliminary schematic diagrams of each space, total area requirements for the project are likely to be more accurate.

Full attention to detail as you define the program saves time and money later, and makes the architect's task in developing more efficient designs. Equally important, this is when the project shepherd becomes most familiar with the program, and with the justification for each part. The project shepherd will have the responsibility for "guarding" the program until the dedication ribbon is cut. She or he thus must know when a change or cutback (proposed or necessary) truly will interfere with the curricular goals that are driving the project, and will be called upon to ensure that the program is adhered to, or to fashion compromises that meet requirements of both program and budget.

In the process of developing the program, one helpful way to check your work is to do a trial schedule of classes for the academic program and curriculum you anticipate housing in the new spaces. Schedule all courses and labs into rooms; outline a schedule to accommodate student-faculty research, course material preparation, etc. Check to see if any functions would not have an appropriate space, or if any rooms would be used only sporadically. If some rooms have the potential of being underused, see if you can design a room that would be used more efficiently if it accommodated several functions. Do not forget to account for science and mathematics courses to be taught in other buildings, and for nonscience/math courses using spaces in science facilities.

Gathering the information needed to define the program can be done in many ways, including the use of questionnaires. However, even the most elaborate and detailed questionnaire cannot take the place of face-to-face interviews with users of the building, and with others whose work will be impacted by the project. The project shepherd is responsible for coordinating the process of defining the program, although the compilation will likely be done by someone more familiar with design aspects, perhaps the project manager.

◆

Be open to new ideas; remember—the new spaces will serve the institution for several decades—the needs of today may not be those of tomorrow.

◆

Among those to be interviewed and surveyed are:

- **faculty members** or designated representatives from each of the involved departments
- **senior administrators** with responsibilities for academic program and finance
- **administrators and staff** with responsibilities for operation and maintenance of facilities
- **secretarial and support staff**
- **development officers** with primary responsibility for securing support for the project

- **physical plant staff**
- **management information systems/computer staff**
- **technicians/building support staff**
- **registrar**
- **students** (both majors and nonmajors).

The procedures and policies for collaboration and communication established during your earlier discussions about mission and academic program will continue to serve you well in the process of defining the facility program.

Questions such as the following might be asked:

- How many seminar/common rooms and student study rooms do we need? Would a centralized commons room and/or centralized student study be a space savings? Would it be possible to use hall space that is not in violation of fire codes? Could we provide, in some classrooms, an extra table with chairs for discussion and study set off to the side? Can we use open spaces for communication and informal study without necessarily having to build lots of small, specific spaces?
- What do we anticipate will be our computer needs for the next 10-15 years, and how are our needs integrated with institution-wide planning? Where should hardware be located? Are we taking advantage of the fact that computing can be done from remote locations? Do all computer labs need to be proximally located and subdivided by disciplines? How much sharing of space and equipment makes sense?

You may find it useful at this phase to make a *site visit* to your own campus science facility, and ask:

- How many students and faculty have used this space in recent years?
- Did these students and faculty use the space for its intended purpose, or for some other purpose?
- Can this space be used for more than one function?
- Have typical class/lab enrollments changed to make this space too small or too large?
- Do emerging programs require different kinds of spaces?
- Can new technologies or new teaching techniques be accommodated in this space?
- What is it that "works" in this space?
- What is it that does not work in this space?

Such a local "site visit" is imperative when considering a renovation. Make an inventory of spaces for teaching and research, offices, and storage and support spaces, as well as spaces currently used "illegally" in corridors.

In defining the program, you will need to articulate, in the abstract, all the spaces that will be needed in the future, for what purposes they will be used, how they will be used, and by whom. The internal physical and environmental needs of each space, and any essential and desired adjacencies (what should be located next to, near and/or on the same floor) will also be defined in general terms at this time. Consider imaginative

approaches to the use of space, anticipate how spaces will be inviting to students, staff, and faculty. Think of how the spaces will facilitate communication, interaction, and exchange between departments, members of student and faculty research teams, and faculty researchers. Also, try to anticipate how the spaces will accommodate new and emerging interdisciplinary programs and/or expanded undergraduate research programs.

Be open to new ideas; remember—the new spaces will serve the institution for 30 or more years—the needs of today may not be those of tomorrow. Think about how the placement of utilities, how the use of modular planning for laboratories will affect current and future flexibility. (The current anatomist may not need gas or vacuum lines in her laboratory, but in ten years, who knows?) You might establish a subcommittee on the future to ensure that some visionary and risk-taking ideas are brought to the table.

Uses and Cautions.

Since the facility program becomes the basis upon which all subsequent design work is based, its importance cannot be overstated. Faculty should complete the design criteria sheets as thoroughly as possible, using consistent language to communicate departmental needs to the architect and lab designer. It is not uncommon to encounter resistance from faculty and staff the process of defining the program. Whether this is because of a lack of understanding of the total process, or from lack of time, it is the responsibility of the project shepherd to be an aggressive champion. It is a vain hope to imagine that you will be able to identify space needs, project designs and costs later, as you develop design documents.

In defining the program, goals you identify should be for the entire department and division, not just for an individual faculty member with a current research program. Indeed, a faculty member may not be able to have a space designed for her/his special research if that particular field is no longer central to the teaching or research goals of the department or institution. Thinking about retirements and new appointments also must be done from the institutional rather than the departmental perspective. Careful consideration of mission and academic plan in the early phases of the planning process will help establish the foundation for planning from the institution-wide perspective.

Defining the program helps you answer questions about how big and costly a project can reasonably be undertaken and what you will get for that price. It is important for faculty to realize that their definitions of space are for usable space. Usable space translates into a bigger shell, since it does not include the spaces required for the building to function, i.e., mechanical, circulation, and other such systems. Cost and size will be projected based on gross square footage, as well as on net square footage of usable space. It is typical in science facilities for the net assignable space to range from 50-60 percent of the gross space.

Ideally, defining the program and setting the budget parameters should happen before the public phase of the fund-raising campaign is underway. This avoids a heavy investment of time by development officers in preparing plans for a fund-raising campaign and by the architects in developing designs—neither of which might be feasible once the program is defined.

You will be able to determine if a feasibility study will be needed after the facility program is complete. If the project is complex, perhaps with challenging decisions about siting or in regard to renovation options, you will need to undertake a feasibility study. If your choice is obvious, if you know that you must build a new facility, you are ready to move directly to developing the design and construction documents described after the next section.

Case Studies. The case studies that follow illustrate how three different institutions (a two-year public college, a four-year private college, and a major private research university) have developed spaces that reflect their mission and identity, and accommodate the facility program as defined by the building users and approved by the project team. They show how a carefully defined program sets the parameters for design.

The Facility Program.

This specifies, on a room-by-room basis:

◆ **number, size, and type of spaces**

- Laboratories for research and teaching
- Laboratory support and service areas: equipment rooms, storage rooms, washing and preparation rooms, controlled temperature rooms, darkrooms, tissue culture rooms, sterilization rooms, etc.
- Offices for faculty, departmental administration, etc.

◆ **architectural elements**

- Doors
- Windows
- Floor finishes
- Ceiling finishes
- Wall finishes
- Floor-to-ceiling height

◆ **environmental conditions for each room**

- Temperature range and tolerance
- Humidity range and tolerance
- Room pressurization
- Special lighting
- Supply or exhaust air filtration requirements

◆ **adjacency requirements**

- Desired office-to-laboratory relationships
- Support spaces that need to be adjacent to labs
- Laboratories that need to be in close proximity to other laboratories
- Opportunities for shared equipment and support spaces
- Opportunities for multiple use of laboratories

◆ **equipment needs**

- Group I equipment (provided within the construction budget): fume hoods, autoclaves, glassware washers and driers
- Group II equipment (owner-furnished): refrigerators, incubators, centrifuges, spectrophotometers, etc.

  (Where possible, the electrical power and laboratory services for each piece of equipment should be identified.)

◆ **services**

- For each laboratory space, capacities, volumes or other measures—such as amperage, voltage, grounding requirements for electrical connections, pressure for gases, temperature and flow rate for chilled water, and other features. Also to be included are service for natural gas, vacuum, air, hot and cold water, purified water, chilled water supply/return, and centrally piped gases such as nitrogen or argon.

◆ **chemical safety**

- Chemicals to be used in individual laboratories are inventoried.

◆ **code requirements**

North Shore Community College Health and Science Building

Danvers, Massachusetts

Architect: Perry Dean Rogers
& Partners
Boston, Massachusetts

Size:

Net Square Feet	
Laboratories	11,800
Offices	8,857
Student Services	15,500
Classrooms	10,568
Total Net Square Feet	46,725
Total Gross Square Feet	68,000

Construction Cost: $4,500,000

Completion Date: August 1994

A bird's-eye view of the major architectural skylight structures which fill interior spaces with natural light.

North Shore Community College (NSCC) serves the metropolitan communities northeast of Boston, Massachusetts. The college is an open-admissions, comprehensive community college which provides freshman and sophomore levels of academic instruction in preparation for transfer to a baccalaureate granting institution or career preparation into a variety of occupational fields. NSCC operates three campuses, each focusing on a general course of study. This case study features the NSCC Health and Science Facility in Danvers, Massachusetts.

Health services, nursing skills, and physical therapy are among the primary disciplines the college offers.

The College's Mission

Health services, nursing skills, and physical therapy are among the primary disciplines the college offers. To service this agenda, the college obtained a 50,000 square foot light industrial building situated on a 66-acre rural site in Danvers, Massachusetts. The first objective in developing this campus was to renovate the existing building into a facility serving all of the fundamental requirements of a commuter college. The program was not unlike a commercial mall in that student services and administrative requirements were needed under one roof. Bookstores and cafeteria would be adjacent to science labs and faculty offices.

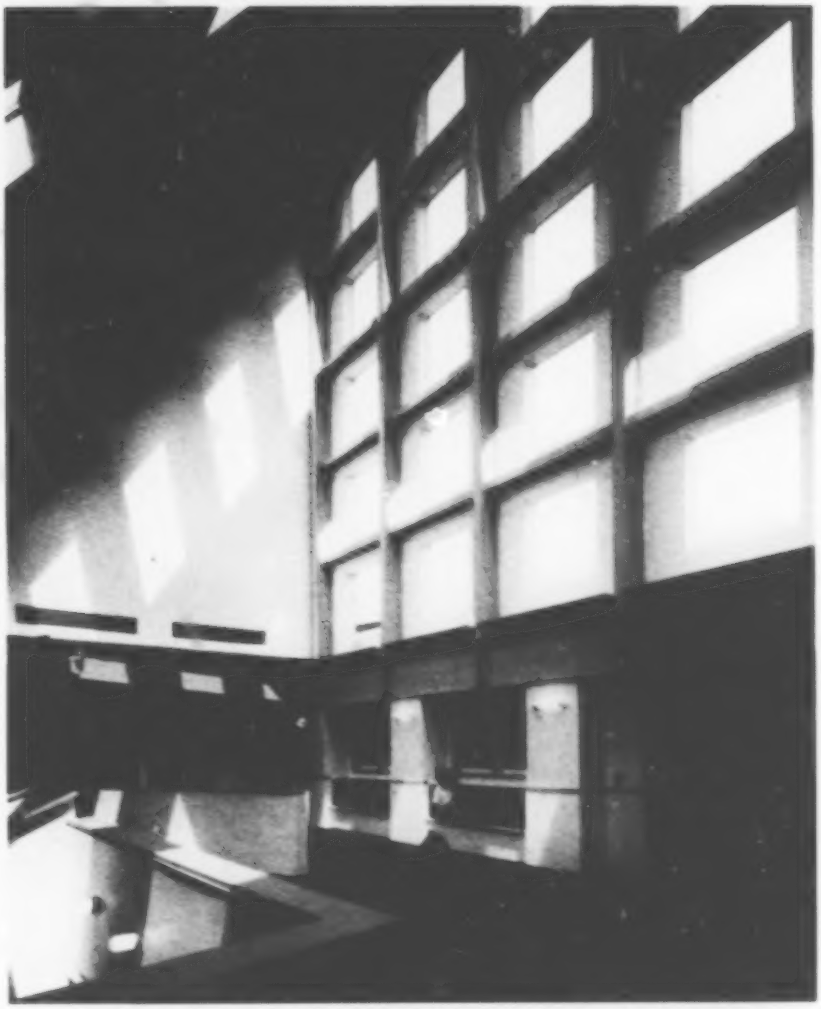
The Building Organization

To accomplish the program established by the college, a second floor constructed within the existing envelope was required. Critical to its success was the need for numerous informal areas for students to gather, study, and relax in pleasant, naturally lit environments. Central focal points highlighted with large skylight structures were located in the middle of the building to bring sunlight into the main gathering areas.

The building serves the study of radiology, respiratory science, nursing skills, occupational and physical therapy, biology, chemistry, mathematics, and biotechnology. Because students commute to the school, their time for getting to know one another is limited to time between classes, or going to classes. In response to this condition, the college wanted to provide places for conversation along primary corridors, student lounge areas, and a large student dining area.

The building is organized in zones, much like a campus is organized in buildings. The administrative offices are off the main entry lobby, yet students are led down a neon lit corridor to the major classroom area. Once through this zone, open areas and large skylight structures provide places for interaction and informal gathering. The types of spaces are visually apparent. The bookstore is contained within a large glass enclosure; teaching areas are viewed through double-hung windows along the arcade.

The 100-seat lecture hall is equipped to allow visual and audio between all teleconferencing centers on the NSCC campuses.



As a commuter college, it was critical to create spaces inviting students to pause en route from their car to the classroom; a view of the second floor student focus area.

The State Planning Process

The planning process for this project followed the guidelines established by the Commonwealth of Massachusetts. In 1990, a comprehensive master plan of the project was prepared by the Massachusetts Division of Capitol Planning & Operations. Along with the master plan, a program study reviewed each space's requirements and provided a complete cost estimate. These documents were intended to be used for legislative funding approval, however the state reduced its support of public education and the project was postponed until funding through the Massachusetts Health Education Authority (HEFA) was secured.

Critical to its success was the need for informal areas for students to gather, study, and relax in pleasant, naturally lit environments.

The Goal

The goal of interior planning was to provide open spaces, student seating, and interior windows looking out of the public spaces in all classrooms. The bookstore is on the right.

The health care community of NSCC has within one facility all of the necessary requirements for a self-contained campus. As the initial building on this campus, people had to be convinced it was both enjoyable and worthwhile to travel to this location for their educational goals. The facility is a tribute to the perseverance of state educators and their vision of an educational environment that fosters both high academic goals and strong interaction among students and faculty.

Reed College Arthur F. Scott Chemistry Building

Portland, Oregon

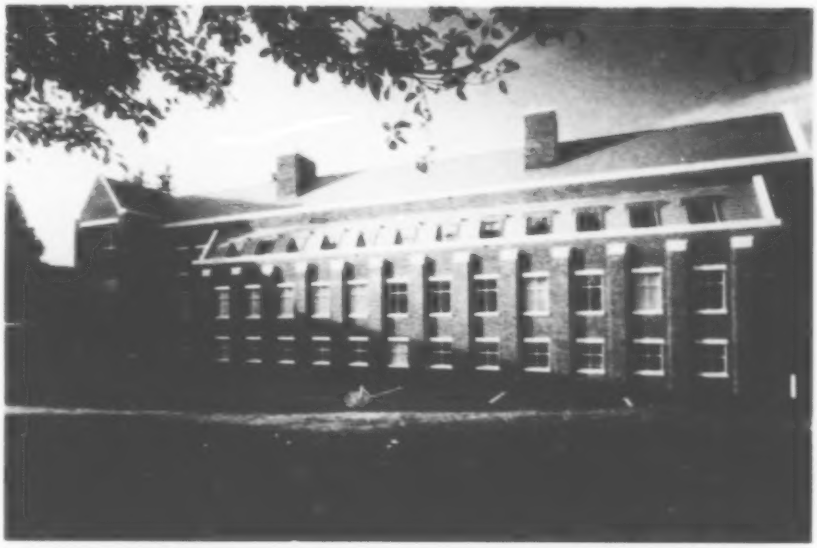
Architect: Zimmer Gunsul Frasca Partnership
Portland, Oregon

Size: 50,000 Gross Square Feet

Net Square Feet	
Research Labs/Offices	10,330
Teaching Labs/Support	7,300
Teaching/Research Support	5,550
Admin. Offices/Support	2,548
Total	25,728

Construction Cost: $8,260,000

Completion Date: September 1992



The Chemistry Building serves as an important extension of the Reed College Science Quad.

This 50,000 gross square feet (GSF) building designed by Zimmer Gunsul Frasca Partnership houses teaching laboratories for inorganic, organic, and physical chemistry, in addition to research laboratories, offices for faculty and thesis students, computer and general classroom space. The building incorporates 18 labs, 21 offices, two computer rooms, conference rooms, classrooms, and lounge areas.

Dedicated laboratory and office space for emeriti faculty and senior thesis students reflects the Reed College "hands-on" approach to learning.

Science Complex

Adjacent to the physics/biology building and the former chemistry (now psychology) building, the site for the new chemistry building serves as an important extension of the existing science quad. The building is integrally linked to the biology/physics building by a 100-foot tunnel. The biology/physics building is, in turn, attached by a covered walkway to the Hauser Library addition—designed by ZGF to unify the dispersed Reed College science collections.

Modular Design

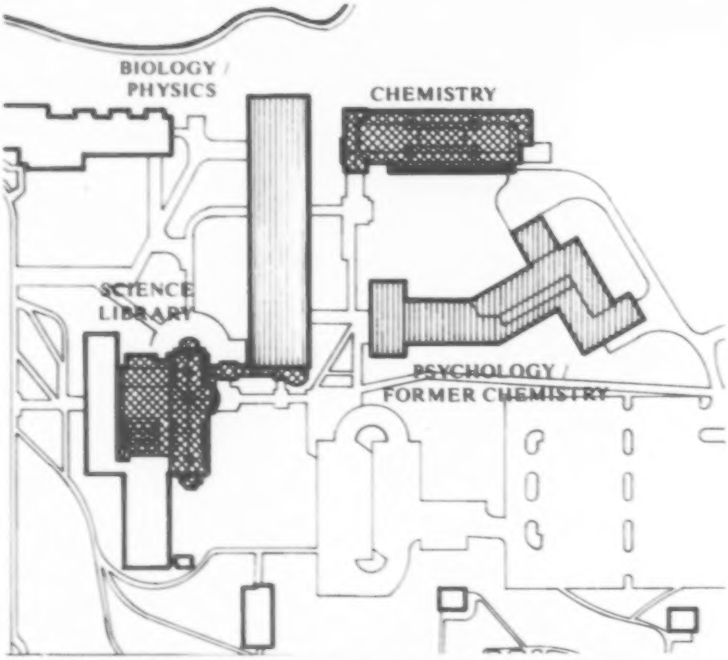
A stringent budget contributed to the simple, straightforward design solution. The building has a four-story brick and precast exterior, with concrete tile roof and copper detailing. Laboratories are located on both sides of a single corridor, with lab support interspersed between labs, to achieve maximum flexibility. Laboratories and offices are designed as modules intended to increase the future flexibility of the building. One of the most distinctive elements of the modular plan is dedicated space for senior chemistry majors. Each chemistry major has space set aside, outside of the laboratory, for studying and thesis preparation. In addition, space is provided for students to set up and conduct experiments over a period of weeks without disruption. Emeriti faculty also have dedicated laboratory and office space.

Interaction

Interaction spaces were specifically designed throughout the facility. The light, open lobby serves as a public place for campus gatherings and receptions. The departmental meeting/conference room is also used by other departments across campus. Bench window seating at the end of each corridor provides students with a place to congregate near faculty offices. Blackboards in the hallways are actively used by students and faculty alike to work through science problems and as areas for group study. A student lounge on the fourth floor is open at all hours.

Safety

Safety was a primary concern in the design and layout of laboratory spaces. Teaching labs are connected to the more advanced research labs and to student offices. Faculty offices are situated so that professors have visual contact with all labs in their areas.



Connections between the Chemistry Building, Biology/Physics Building and Hauser Science Library, make this a complete science complex.

The lobby is one of many planned interactive spaces that allow students to gather and conduct group study sessions. The lobby is also used for campus-wide receptions and orientations.

This arrangement was designed specifically to encourage interaction between faculty and students at all levels of study. Windows in each laboratory allow faculty to monitor activities from any room. This feature also plays an important role in student safety while working in the labs after hours.

Efficiency

Another important consideration was the sharing of equipment between students and faculty. For instance, the advanced organic/inorganic chemistry laboratory is adjacent to the introductory chemistry laboratory and connected by interior doors to allow students from both laboratories to share common instrumentation. The tunnel connection between the chemistry and biology/physics building also permits interdepartmental sharing of equipment.

The modular lab plan and windows between laboratories allow faculty to monitor as many as 24 students simultaneously.

University of Chicago Kersten Physics Teaching Center

Chicago, Illinois

Architect: Holabird & Root
Chicago, Illinois

Size:

Net Square Feet	
Laboratories	24,500
Offices	1,500
Student Services	3,000
Classrooms	11,000
Total Net Square Feet	40,000
Total Gross Square Feet	67,000

Completion Date: August 1984

Cost: $7 million

Exterior perspective.

The Kersten Physics Teaching Center at the University of Chicago houses undergraduate and graduate instructional and research space with particular focus on astrophysics. The creation of a new facility was seen as an opportunity to raise the level of research, and establish a new image for the sciences on campus.

Context and Site

The University of Chicago was founded in 1883 with the original buildings constructed of limestone in the collegiate Gothic style. As an urban campus, the university's founders looked to Cambridge and Oxford for its model. The buildings were constructed at the street edges to define internal quadrangles and courtyards. In the 1980's, a new science quadrangle was planned for the block just west of the original campus. This plan included the demolition of a number of utilitarian service structures and the construction of two new science-related buildings, a Science Library, and the Physics Building. The Physics Building was the last building to be constructed and therefore became the final piece to complete the enclosure of the new quadrangle.

Program

The original statement of space requirements included 15 teaching laboratories, independent research laboratories for upper division students, limited permanent research laboratories for ongoing faculty research, classrooms, offices, seminar space, and a 220-seat demonstration auditorium. During preliminary discussions, the faculty raised two principles which they felt were critical to the ultimate success of the building: first, the need to organize the spaces in a way which would foster a spirit of interaction between faculty and students so that learning could continue outside the laboratory or classroom; second, the need to express the building's purpose on the exterior so those who passed the building might be drawn inside. Both principles were major influences in the final organization of the building.

Building Organization

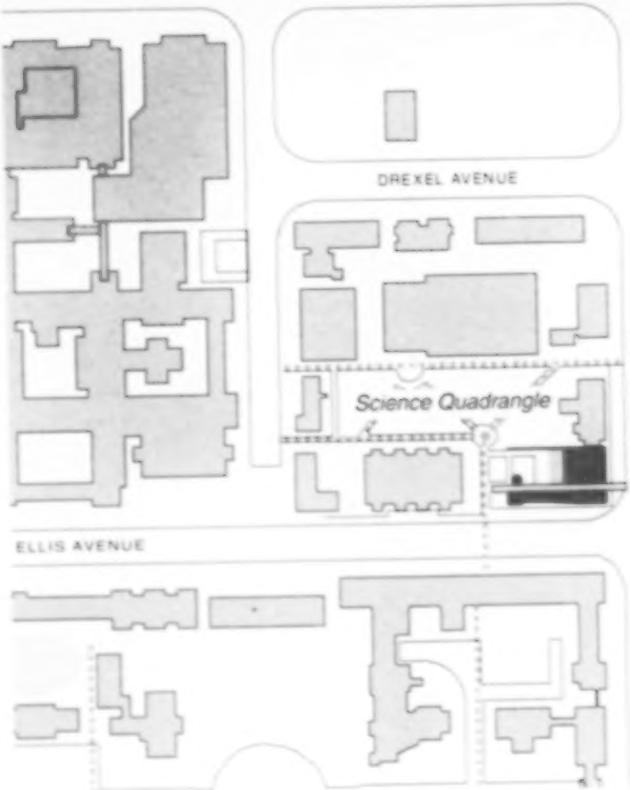
The building is organized along a circulation spine which is open for three floors and is exposed to the science quadrangle. This spine provides the public area where students and faculty naturally congregate between classes. Open stairs, special displays, and experiments help to enrich this area and keep it active. The exterior exposure to the quad has a double benefit, it allows natural light into the public space and makes these activities visible to the exterior at night.

The building's vertical organization follows a logical pattern of use. Spaces used by the highest population of students (large auditorium, undergraduate teaching labs, student services) are located at the grade level for easy access. More sophisticated research labs are located on the upper floors where they have direct access to the rooftop experiments. Faculty and administrative offices occupy the second floor which is connected by a bridge to the Research Institute.

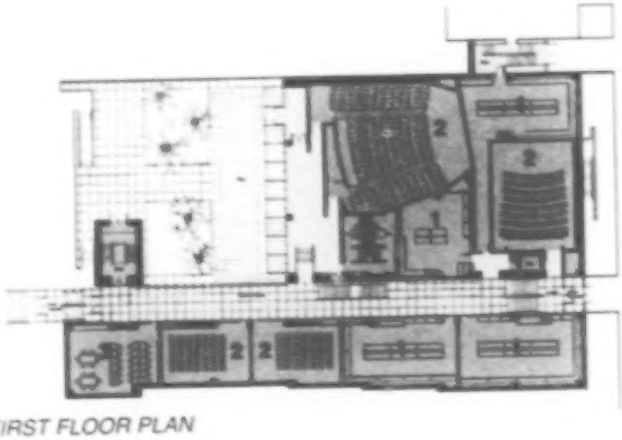
The building's exterior form is a direct expression of its internal organization, with larger floor areas at the base which diminish with each succeeding floor. This results in a series of terraces which provide exterior areas for experiments in astrophysics.

Individual Spaces

Over half of the total net square footage of the building is taken up by instructional and research laboratories. As a result, this component was a focus of much attention. Since many of the experiments are light-sensitive, special consideration had to be given to the control of natural and artificial



Original Campus Quadrangle



FIRST FLOOR PLAN

1. *Laboratories*
2. *Classrooms*
3. *Student Services*

light. Window openings are limited and controlled with blackout shades; variable up-lighting is used to provide a diffuse artificial light, and lab finishes were selected for durability and low reflectance. The 220-seat auditorium was specially equipped for lecture/demonstration. A movable demonstration cart can be set up in a prep area, rolled into place, and attached to a fixed podium which contains all of the lab services. A video camera mounted on a movable track in the ceiling records demonstrations which occur on a horizontal surface and projects them vertically.

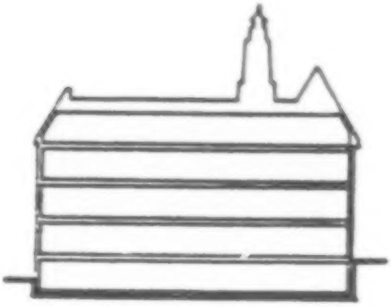
Conclusion

The Kersten Physics Building, received a design award at its completion in 1984 and more recently was nationally recognized as a building that has been in use for at least five years that has successfully addressed issues of site, program, and operational efficiency. The success of the final result can be attributed to the close collaboration formed between the faculty and the planners in the early programming phase of the project. It was during this formative time that guiding principles were established which shaped the building's final organization and form.

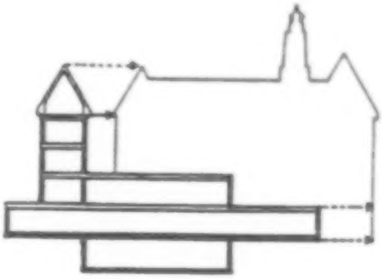
The Feasibility Study.

Based on the information gathered in defining the program, you may have a difficult decision: to renovate, to build an addition, or to build a new building. If so, a feasibility study is necessary. A feasibility study presents different options for renovation or new construction. It will also lay out the potential compromises or advantages in alternate construction solutions. On the basis of the feasibility study, the executive committee, or the body with institutional responsibility for capital expenditures, will make a final decision about the scope and character of the project. The project team, working with representatives from the campus facilities office, architects, contractors, and/or consultants, will be involved in the feasibility study.

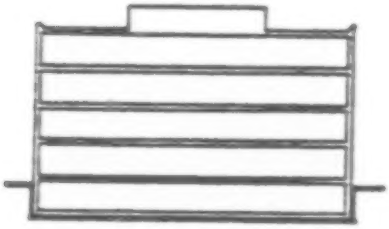
Feasibility. A feasibility study presents the proposed renovations and/or addition(s) as well as the proposed phasing of the construction for the addition(s) and/or renovations. The study often includes several alternatives that address the various goals and objectives established by the college. As part of the feasibility study phase, alternatives are developed including the location of departmental spaces to show how the program spaces fit within each space, the location of the addition(s) and/or the extent of renovation. These alternatives include analysis of schedule, phasing and construction costs.



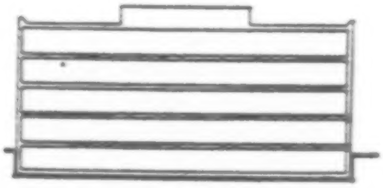
Option 1A: Renovate to accommodate current needs.
Gross area: 84,950 square feet
Cost p.s.f.: $125
Cost: $10,745,000



Option 1B: Renovate to accommodate future needs.
Gross area: 84,950 square feet
Cost p.s.f.: $125
Cost: $10,745,000



Option 2: New construction to accommodate current needs.
Gross area: 93,200 square feet
Cost p.s.f.: $186
Cost: $17,341,000



Option 3: New construction to accommodate future needs.
Gross area: 115,312 square feet
Cost p.s.f.: $184
Cost: $21,218,000

The feasibility study typically includes the following components:

- Executive summary
- Building analysis
- Program summary
- Project description
- Construction phasing
- Preliminary schedule
- Cost estimate
- Code and zoning analysis
- Appendices

The executive summary highlights the major elements and options developed by the study. The intent of the executive summary is to allow individuals, such as the board of trustees, the president, vice president, etc., to quickly understand the major conclusions of the study.

The building analysis includes an analysis of the existing building elements, including architectural (exterior enclosure, interior finishes and laboratory equipment), structural, plumbing/fire protection, heating, ventilating, air-conditioning and electrical systems. This analysis includes an evaluation of existing elements and recommended improvements.

The program summary includes a summary of the program information developed by the institutional teams and architects.

The project description quantifies the scope of work required to accommodate the program in existing facilities, and/or in new construction. This section typically includes alternative schemes which explore different locations of the various departments and different siting alternatives for the addition (if required).

The construction phasing section includes a description of alternative phasing strategies, and the amount of disruption each would bring to the existing occupied spaces. Some institutions prefer a concentrated disruption for a short period of time and others prefer to minimize disruptions, and accept a longer duration.

The preliminary schedule includes a bar chart schedule which includes all major tasks required to complete the renovation and/or addition(s). This schedule includes alternative phasing strategies, if appropriate. "Major tasks" would include all design and documentation as well as all demolition, renovation, relocation, and new construction activities.

The cost estimate section includes a narrative describing the renovations and/or new construction, as well as advantages and disadvantages of the renovation and addition alternatives previously described. The cost estimate section also includes a detailed estimate of the entire construction and/or renovation work including appropriate contingencies for the preliminary nature of the information. Cost estimates, when prepared by a professional cost consultant at this early phase of the project, are generally within 20 percent of the actual bid prices if appropriate contingencies are included.

The code and zoning analysis includes a summary of all applicable building and zoning codes to which the renovations and/or addition(s) must conform including local, state and federal codes.

◆

As with all your planning, it is important to be objective in a feasibility study, to approach this undertaking with an open mind, and to have an explicit schedule and agenda by which to accomplish the task.

◆

The appendices include a listing of specific issues which must be addressed by the renovations, more detailed drawings of alternative arrangements of spaces within the existing building and the addition(s) or other materials which support the study as required.

The outline specifications section in the appendix provides a detailed documentation of all proposed new construction and renovations, including architectural, structural, and mechanical elements. The intent of this section is to provide information such that a cost consultant can generate a summary of the materials and systems that are planned for the new and renovated spaces.

A feasibility study is both a process and an end product. You undertake such a study to gather the information needed to make the right decision about options in regard to renovating or building new, about the scope of a possible renovation in the context of accommodating the program you have developed, or about siting. New construction has many obvious advantages, such as opportunities to attract donors, lower operating costs, no breaks in class schedules, etc. But this option may not be possible, given your local circumstances.

Begin the feasibility study by using your experience from visiting other campuses and insights gained from defining your program to "visualize" an ideal facility for your campus. Earlier evaluation of *what works* in your current spaces, and understanding what you like or dislike about key spatial relationships that currently exist will advance the feasibility study.

As with all your planning, it is important to be objective, to approach this undertaking with an open mind, and to have an explicit schedule and agenda by which to accomplish the task.

Renovation. In the feasibility study, you will make both a *quantitative* and a *qualitative* analysis of the existing spaces, considering the following characteristics:

- spirit and soul
- "highest and best use"
- life span of HVAC systems
- capacity for expansion
- adaptability
- presence of vibration
- floor-to-floor height
- quality of mechanical space
- building style and age.

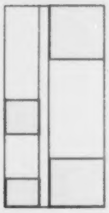
The character of the interior and/or exterior of an existing facility is often a distinguishing part of a campus and contributes to the "spirit" and "soul" of the college or university. Over its lifetime, the building has become convenient and familiar for students and faculty, and is fondly remembered by alumni. It may also have pleasant spaces for work or study. Consequently, you may want to save it since achieving the same effect in new construction can be difficult and expensive.

Since the structure remains largely the same in a renovation, one might think that the loyalty students, faculty, and alumni have toward it will not change. However, renovations do not always turn out that way, and it is wise to decide, as the renovation project proceeds, what parts of the structure contribute so much to the *qualitative* environment that they must be preserved.

You must consider that new facilities for chemistry and biology require large, flexible spaces that provide substantial HVAC, plumbing, and electrical systems support, facilities for mathematics, computer science, and physics also have their own special requirements. Often, existing facilities are not well suited for programs requiring such HVAC or other specialized equipment, and the cost of renovation may be as high or higher than new construction. Not only are large, unobstructed spaces uncommon in older facilities, but available space to run new enlarged mechanical systems is equally rare. An existing facility has a "highest and best use" which may or may not be appropriate for a modern science facility. For example, it is improbable that a new chemistry facility will be easily worked into an existing outdated facility that has low floor-to-floor height and limited available mechanical space.

Upgrading a science facility will increase heavily the demand for campus utilities such as steam and chilled water. If the cost of a renovation exceeds a percentage of the building's value, then an upgrade of utilities may be required to conform with current fire codes. Such an upgrade will also have significant impact on the budget for your project.

Renovation Considerations.



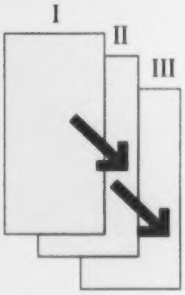
Minor Renovations—No Layout Changes.
Renovations completed in summer

◆ Difficult working conditions (move experiments, equipment).

Floor-by-floor renovations in place

◆ Difficulty working conditions (move experiments, equipment)

◆ Long construction duration



◆ No economy of scale—high cost for small areas of work.

Comprehensive Renovations—Changes to Layouts, Partitions, Hoods.
Floor-by-floor renovations

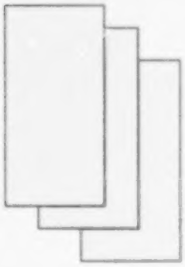
◆ Requires one vacant floor to begin phasing of construction

◆ Disruption to adjacent floors (vibrations, noise, dust)

◆ Plumbing impact on floor below renovation

◆ Extended construction duration—high costs

◆ Cannot easily change mechanical infrastructure while maintaining operation of existing systems.

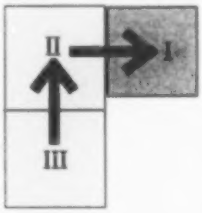


Gut Renovation.

◆ Requires entire building to be vacated

◆ Construction usually exceeds one year

◆ Often done when new construction provides swing space.

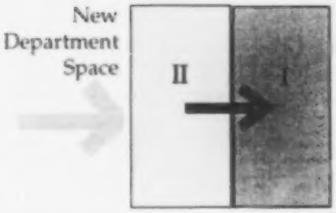


Renovations with Small Addition—Expand Department or Floor.

◆ Addition constructed prior to renovations

◆ Small addition does not provide swing space large enough to facilitate phased construction

◆ Addition may include new mechanical systems, risers, elevators, ADA toilet rooms, etc.



Gut Renovations with Equal or Larger Addition—Added Program.

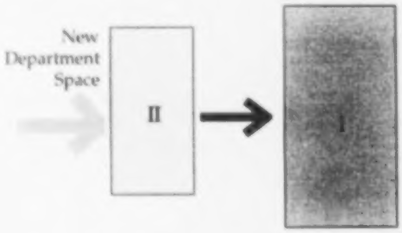
◆ Addition constructed first to facilitate renovation of vacated space

◆ Addition may include highest technical spaces

◆ Addition can accommodate new mechanical systems which back-feed renovated structure

◆ Good value of money to hours lower technical function in renovated space

◆ Phased renovation in vacant space—best use of money.



New Building—Reuse or Demolition of Older Building.

◆ New building usually larger than existing

◆ New building allows for "idealized" layout of department

◆ Reuse of older structure assumes campus need for additional space

◆ Construction does not impact current operations.

Simple Changes. You might consider what kind of spaces can be achieved merely by upgrading the facilities. For example, some program goals might be achieved by "low-cost, high-impact" renovations. Consider the impact of refinishing casework, or of providing new millwork to tie disparate spaces together visually. Painting or adjusting all the lighting can also have significant impact on the learning environment without a significant financial outlay. Executing minor upgrades is usually a clear-cut process of working in and around existing programs. The preceding chart presents renovation options, showing how they range from simple cosmetic renovations done in place, to "gut" renovations, or to a combination of renovation and addition.

Many projects, as can be seen in the stories that follow about renovations, evolve into a mix of renovations and additions. Design solutions to be addressed by renovations must be tailored to the unique characteristics of your particular program and your institutional mission.

Program Disruptions. Another consideration in the feasibility study is the time the renovation work would require and how that would disrupt your classes or research activities. Develop a "project schedule," which addresses the phasing that will be required if the building is to be renovated. Major renovations can have a severe impact on the occupants of the building, and disruptions should be kept to a minimum. Thinking about the project schedule will help you to avoid double moves, if possible, as well as to identify "swing" space during the renovation process. Remember, however, that getting the best long-term facility may mean enduring some short-term difficulties. If swing space is not available, then an addition may be required. An important responsibility of the project team is to propose a feasible renovation phasing plan that addresses all the major milestones.

Codes. In a feasibility study it is particularly important to remember that all renovations required to satisfy current building code requirements must be documented. Building code requirements include safety codes (e.g., number of exits, earthquake and fire resistant construction codes) and access for individuals with disabilities, as required by the Americans with Disabilities Act (ADA).

Costs. Finally, you must include preliminary estimates of construction costs and a description of total project costs for the various options presented in the feasibility study. Total project costs include construction costs, as well as movable furniture, moving costs, site acquisition costs, architect's and engineer's fees, and all other costs that will be incurred for the project. Construction costs are typically limited to costs attributable to "bricks and mortar" and those site development costs required by the project.

It is a common misconception that renovation costs are always less than new construction, given that the existing structure and exterior skin are being saved. Therefore, the allure of conducting a "fast and painless" renovation is quite tempting, but expensive surprises can limit the success of a renovation, since it may lead to disruption of the class schedule, require extensive costs and compromise, and have limited ultimate value to the academic program of the institution.

Additional costs can be incurred as unforeseen conditions are discovered; schedule delays can extend through multiphased renovations. Maintenance and operating costs must be factored into the overall analysis of a renovation project, as must costs associated with hazardous materials removal, an increasing part of renovation projects.

What to do with a vacated facility can pose a problem if the decision is made to build. Buildings can be demolished if in irreparable condition, "moth-balled" if they are to be utilized at a later date, or renovated for another use. All of these options have a cost impact on the overall project.

Different levels of renovation lead to different levels of costs, such as cosmetic work, full gut renovations, mechanical infrastructure work, life safety code upgrades (triggered by the percentage of proposed work within the overall facility), ADA/accessibility, hazardous materials removal, and structural/vibration issues. The changes required by codes and upgrading mechanical systems may consume floor space and thus result in less usable floor space after the renovation than before.

Any adjustments required because of financial constraints must occur uniformly; the perceived quality of the completed renovation will only be as good as the poorest conditions. At each step in the process, you must reevaluate and be willing to adjust your expectations accordingly.

OUTREACH TO THE K-12 COMMUNITY

The Canisius College Story

The seminal 1983 report, "A Nation at Risk," by the U.S. Department of Education, noted that science programs in American elementary and secondary schools had no links to science programs in colleges and universities. Only in scattered areas were the most adaptable facilities in American science education, the college-level laboratories, used to link training in the sciences throughout the three educational levels—elementary, secondary, and higher education. Canisius College in Buffalo, New York, decided it would start a program linking its science facilities with those of the local elementary and secondary schools. This decision soon changed the planning for renovations that were underway at Canisius.

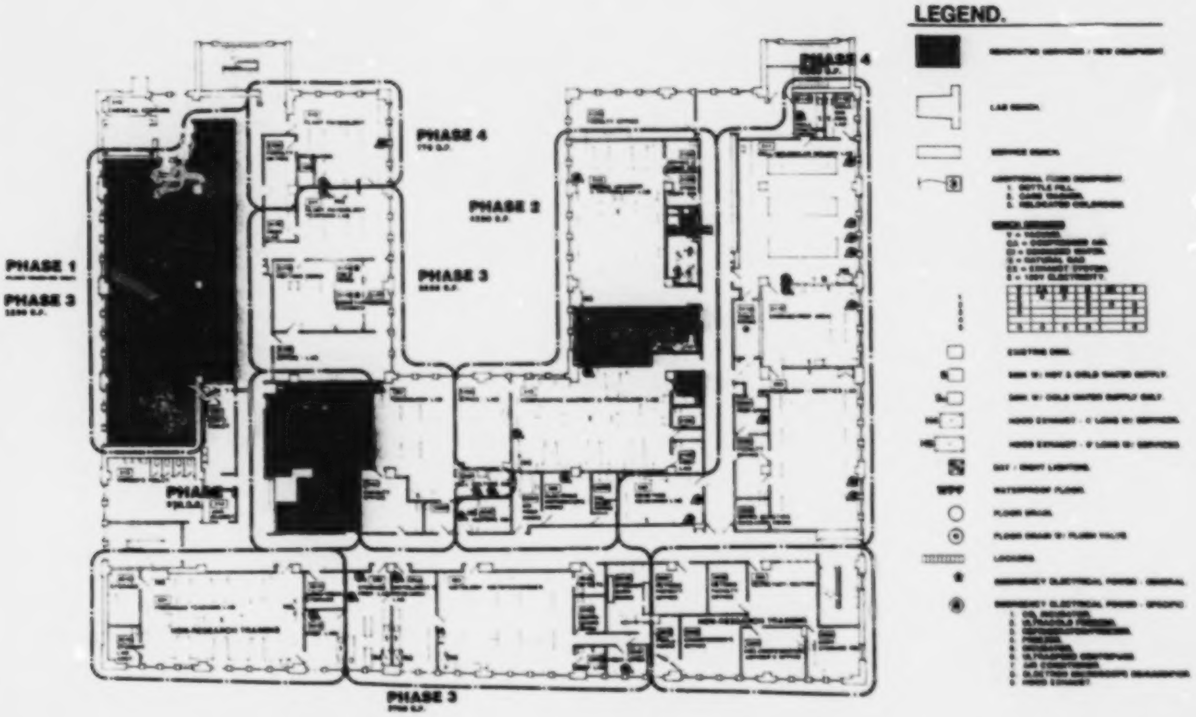
When we began our K-12 outreach program, the science faculty did several things: first, we started having science teachers from local schools come to campus monthly to join us for experiments and discussions of science and teaching science. Second, we held week-long summertime programs in science experimentation for local elementary and high school teachers. Third, we sent undergraduate science majors to local elementary and high schools to be assistant teachers (they would, after all, be the next generation of science teachers). Finally, we invited teachers to bring their students to the college during the academic year for one-day, hands-on science laboratory workshops.

As the college began to plan to renovate its science facilities, some of us, during the programming phases, prevailed on the administration to incorporate the school collaboration programs into the new design, making it clear that, fortunately, including these programs would not place any new needs for space on the facility. As we proceeded, it also became clear that a simple request that faculty use a space for a special project was a *design quality* that needed to be carefully considered in the programming phase. Even though they have no direct influence on the arrangement of the space or the architecture, special programs cannot be left aside in planning phases, for the risk of being "built-out" of the resulting facility. All that we requested was that the project team bear the school-linking project in mind when it thought about how the newly renovated space would be used. Had it been left out, the collaboration project would have been more likely to wither-away with time, faculty changes, or temporarily flagging interest.

While the outreach program did not require actual space, it required spaces that showed that science is a serious affair. It is important that necessary supplies be nearby and efficient to use so that a professor demonstrating an experiment does not need to run to different places for the proper equipment in the middle of the experiment.

A college-school collaborative laboratory was designed to be a shared space in the biology department. Of course, the real purpose of our labs at Canisius is to teach the college's own students, but the collaborative program has brought rewards to everyone. Local high schools that offer advanced-level biology classes are able to arrange to bring their students to the college, as often as twice a semester, where Canisius faculty lead the laboratory activities required by an advanced biology curriculum. Most importantly though, the inclusion of the collaborative program in the design considerations as one faculty member said "removed any excuse for why faculty could not make links in science with other teachers, present and future, as the *Nation at Risk* study recommended." Really, no additional designing was necessary, nothing beyond what any scientist wants in a lab: that it communicate the process of scientific investigation to anyone who sees it.

CANISIUS COLLEGE RESEARCH FACILITIES RENOVATION



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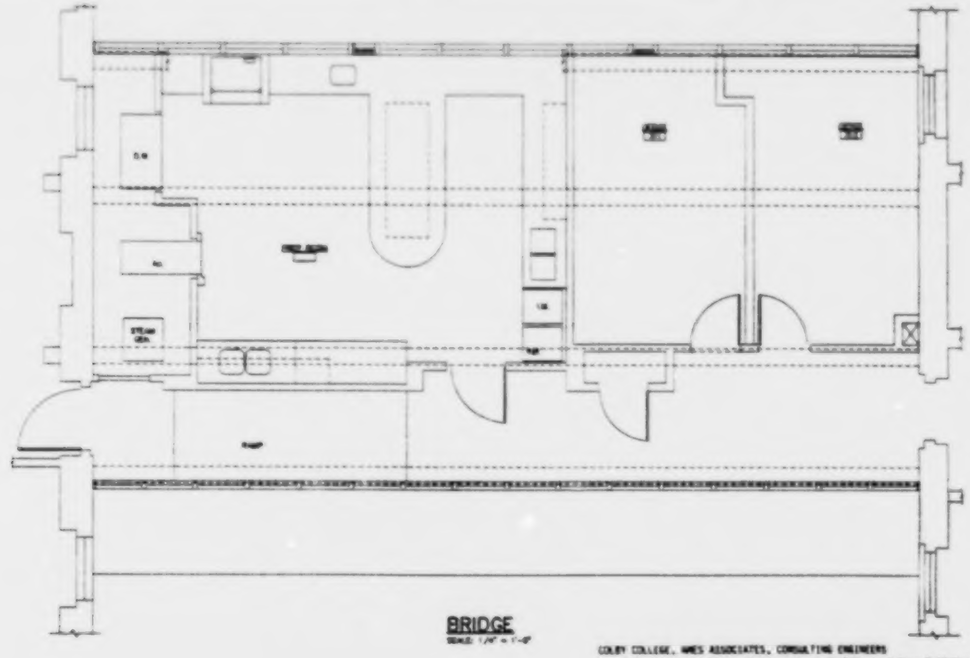


COLBY COLLEGE, AMES ASSOCIATES, CONSULTING ENGINEERS
Third Floor Level - Bridge between Keyes Building and Arey Building

CONNECTING THE DISCIPLINES

The Colby College Story

In 1990, Colby College's Division of Natural Sciences decided to develop an interdisciplinary program blending biology and chemistry. The division had just completed a self-examination study and a "Plan for the Sciences in the 1990's," which called for the development of interdisciplinary programs. Expanding from a collaborative course taught by chemistry and biology called "Molecular Genetics," —already a popular course on campus and in student evaluations— the faculty worked together to add classes in "Biomolecules" and "Metabolism and Bioenergetics." The chair of the Division of Natural Sciences called it "an unparalleled opportunity for students and faculty to explore the primary literature and use state-of-the-art laboratory techniques and equipment to enhance training in this exciting and rapidly expanding discipline."

As renovation and construction projects, supported by a grant from the Howard Hughes Medical Institute, were considered to support the curricular innovations in the "Plan for the Sciences in the 1990's," we arrived at the idea of building a literal bridge between the two departments in the two buildings. Faculties of the two departments thought that the links created by joint committees and team-teaching were not sufficient to forge a full interdisciplinary enterprise. Since the two departments were housed in separate buildings, further distanced by the vagaries of the weather in long Maine winters, the two faculties feared an inertia effect might occur, resulting in both departments gravitating inward and returning to their own traditional material. Adding a third-floor skyway to a second-floor structure became a high priority in reinforcing the strides that were made to figuratively "bridge" the departments with the development of an interdisciplinary program in "cell and molecular biology/biochemistry."

The skyway built between Keyes Chemistry Building and Arey Life Sciences Building added more than simple access. It serves as a "relations builder," holding two faculty offices and a modern laboratory "prep" room that includes equipment shared by both departments: a large autoclave, glassware washer, fume hood, refrigerator for flammable materials, extensive benchwork, and cabinets for storage. In addition, there are hallway cabinets for widely used, expendable supplies. Students and faculty of chemistry and biology are able to move easily from labs and offices in one building to labs and offices in the other on a pathway that encourages them to associate more easily with one another. As the costs of laboratory equipment rise, the skyway allows for easy access to, and extensive use of, commonly shared equipment. Think of it: this is the building of a biochemistry program in a real-world setting where learning takes place, not just during class time, but also in conversations with a variety of people whom they see in the corridors and work near in the laboratories. This is experience as the best teacher, thanks in part to architecture.

Additionally, and what is very valuable to the college, the plan for the skyway facilities was instrumental in recruiting a biochemist to the biology faculty. She even said that the skyway bridge's literal and figurative links between the departments was a "deciding" factor in her acceptance of the position at Colby. She reported that the physical layout as well as the opportunity to share easily both equipment and expertise with other members of both departments who are involved in the program, functioned extremely well as she began her teaching and research program at Colby. Another sign of the program's success was that by the spring of 1994, 13 students had declared a full-time focus in the new program. The skyway underscores for the college and visitors alike, Colby's commitment to interdisciplinary education—it provides both an emblematic linkage of biology and chemistry and a functional merging of the resources of both departments.

ADAPTING AN OLD PSYCHOLOGY LAB FOR NEW DEVELOPMENTS

The St. Olaf College Story

Psychology as a discipline is changing in several ways, but most notably, it is expanding. At St. Olaf College, we were not going to be able to expand our departmental space accordingly, but we did renovate it to incorporate the discipline's latest developments into our students' learning.

On a broad scale, the study of psychology is changing in two ways:

(1) the growth of cognitive neuroscience as a part of psychology has required specialized studies and labs that resemble those of the "hard sciences."

(2) the cooperative work environments in industry and research centers require that students be trained in collaborative research so that they are well prepared to work on teams.

Add to those the computer-assisted data acquisition that makes possible more research—by students as well as faculty—in perception, neuropsychology, conditioning and learning, and cognitive psychophysiology. These recent disciplinary and technological developments challenged us as a department to think about the learning environment for our students. We developed several goals: first, we wanted our psychology majors to have high-quality research experience in the areas developing most rapidly in the discipline; next, we wanted both majors as well as general students to understand psychology as a science, and the relationship between the science of psychology and the applications of psychology. We wanted all students to have hands-on research experiences, with the opportunity to learn about ethical research principles as they did science.

Our old spaces were sorely behind advances in the discipline. Our building is 70 years old, and among other problems, the department was spread out over two floors, making collaborative work difficult. We had no spaces for sensation/perception (neuroscience) experiments, which are a dynamic aspect of expanding psychology; our animal quarters were a long walk from the labs. When we tried to record psychophysiology signals, we had 60 cycle interference so bad it sometimes obliterated the signals. All this needed to change.

As we began to plan the renovation of our current departmental spaces, we also designed a new introductory course to introduce the discipline to students in interesting ways. We called our new program, "Psychological Foundations," and integrated into it a laboratory component that had not traditionally been a part of our introductory courses. By supplementing the lecture with lab experiences, we could provide students with a sound theoretical framework, introduce them to method and apparatus, and allow for data collection. Further, we decided to include a written requirement for the lab, and to require the reading of a contemporary research article of primary literature, so students would see how laboratory experience fits into current research in the field. Partial funding for the renovation was provided by a grant from the National Science Foundation's Academic Research Infrastructure Program.

On the one hand, the renovation and new changes posed several challenging problems, such as how to cut a trench through the concrete floor to route the ventilation for the neuroscience dissection room, or how to solve the problem of the remote animal care areas. But on the other hand, we surprised ourselves with some of our solutions. For example, we wanted a grounded Faraday Cage in the psychophysiology lab, but we did not want it to look like a "cage." Who would want to talk in there? We decided to configure the Faraday Cage to look like a place that evokes images of calm and relaxation here in the Midwest, a screen porch attached to a farmhouse!

The key to the success of the project was the willingness of all members of our community to work together; everyone understood that the project served the common good.

MECHANICAL SYSTEM RENOVATIONS

The University of Richmond Story

At the University of Richmond, we decided it was time to renovate the science center's fume hood ventilation system, both updating it and expanding it with more hoods to accommodate the growing interest in science on our campus. It was already obvious that our fifteen-year-old constant-volume-hood system was unreliable and needed to be reworked. It had problems maintaining consistent face velocities, proper pressurization within the classrooms, and adequate dehumidification. Furthermore, the existing ductwork and air handling systems were not advanced enough to handle the 24 new hoods we wanted to add to the system.

We faced an additional challenge with the renovation work—the substantial impact it would have on teaching and research activities in the science center. Renovation would take time and stop classes, but in the long run it would offer substantial benefits. Eleven laboratories would be modified, and nine of our 27 science faculty members who were then conducting research would, at a minimum, be slowed down in their work, as would approximately 160 students working with them or on their own. On the other hand, everyone would stand to benefit from additional fume hoods, as teaching laboratories would get new hoods to accommodate the increasing number of students in the sciences. The NSF Academic Research Infrastructure Program, which supports research and research training facilities projects, provided part of the support for the project.

As we undertook to change the system, we had to minimize the disruption of classes and research for our faculty and students; we canceled a summer session and hoped that 90 days would be enough time to complete the project. Fortunately, that was all we needed.

We installed variable-volume-flow hoods with occupancy sensors. This allows us to take advantage of diversity of use, the simultaneous use rate. In fact, the ductwork already supported a 70 percent diversity rate, more than adequate for the new system; we just added controls to coordinate operation of the hoods, exhaust fans and supply air quantities, thus maintaining a constant negative static pressure in the laboratories. We also installed occupancy sensors in 40 existing hoods, and coordinated them with the 24 new hoods we installed. These sensors reduce the face velocity (air flow) of the hoods to 60 feet per minute when no one is using the hood, compared to the optimal air flow rate of 100 to 125 feet per minute when the hood is in use.

After a summer of renovation, we have a safer and more consistent environment for all occupants of the building. Faculty are so well satisfied with the result that they now neither feel nor smell the need for additional ventilation, and they routinely close the hood sashes when they are finished working. This, combined with our better equipment, has worked out to make our actual air flow rates fall to 50 percent of the original capacity of the ductwork, with the average maximum air flow rate at 35 percent. Better temperature and humidity conditions exist throughout the building, additional research and teaching hood space is available, odor problems have disappeared. Lastly, we are pleased to report that the net result of the occupancy sensors, coupled with the efficiency of the variable volume hoods, is that we are using 61 percent less energy than a comparable constant volume system.

NEW LABS FROM OLD: RENOVATIONS FOR A DISCOVERY PROGRAM

The College of the Holy Cross Story

In 1989, the Department of Chemistry at the College of the Holy Cross developed a laboratory-centered approach to teaching general and organic chemistry called "Discovery Chemistry." In traditional classes, chemistry students learn theories and principles first in lectures and then verify them in the laboratory. However, Holy Cross students now "discover" chemical principles in the lab session. Their findings then form the basis of subsequent lectures. In many ways, "Discovery Chemistry" follows the pattern of discovery inherent in the scientific method, giving students an understanding of both the content of chemistry and the process by which it is acquired.

We knew when the program began that our facilities would not meet its needs. Our laboratories, constructed in 1959, were traditional, large open lab rooms on two floors of the science hall. Sixty students worked in a lab at a time. The large size of the rooms and the fixed lab benches prevented students from breaking off into small groups for discussion or for data analysis with modern instrumentation. Hence, in 1990, the college converted four old labs—two chemistry teaching labs (used for both general and organic chemistry) and two adjacent faculty research areas—into two "Discovery Complexes." This renovation was funded by the W.M. Keck Foundation.

In the renovation work, we divided each original laboratory into a smaller laboratory and a prelab room, while faculty research space was converted into instrumentation rooms. The Discovery Complexes, each of which supports the work of 30 students, integrate contiguous areas for experimentation and instrument-based investigations, small group discussions, large group discussions, and data presentation. Discovery Complexes on the second and third floors are identical and are connected by a spiral staircase in their instrumentation rooms. With several sections in each course, we have been able to accommodate up to 300 students in general chemistry and 240 in organic chemistry each semester.

The Discovery Complexes have several features that complement and enhance our innovative approach to teaching chemistry. The prelab room, because of its movable tables and multimedia facilities, can support group interaction, active participation in discussions, and the display of pooled data. Having the prelab room and the laboratory adjacent to each other promotes frequent use of the prelab room for discussions and data analysis. The spiral staircase which connects the two instrumentation rooms makes it possible for a student to carry chemical solutions between areas without going through the hallways. The instrumentation room itself is laid out in U-shaped bays. Each bay contains a set of instruments. The multiple bays and the U-shape of each help to control the flow of students while facilitating group interaction during experiments.

Focusing the science curriculum around Discovery Chemistry was part of the story, but helping the project reach its potential required adapting the spaces in the science facility. Without the architectural changes, part of the value of the curriculum would have been lost.

MATHEMATICS AS A LABORATORY SCIENCE

The Mount Holyoke College Story

In 1988, following upon two decades of probing the possible uses of computation in college mathematics and statistics, the Department of Mathematics at Mount Holyoke College made the decision to incorporate computer experimentation and laboratory activities into its curriculum. Faculty considered several options and went through several phases before making curricular or physical changes. At first, they examined other innovative mathematics programs such as those at Dartmouth and Hampshire Colleges; they then rearranged some of their classroom spaces into labs; and finally, three years after the initial decision, they undertook fuller renovations where a coordinated and coherent intermingling of laboratories, classrooms, and offices was achieved.

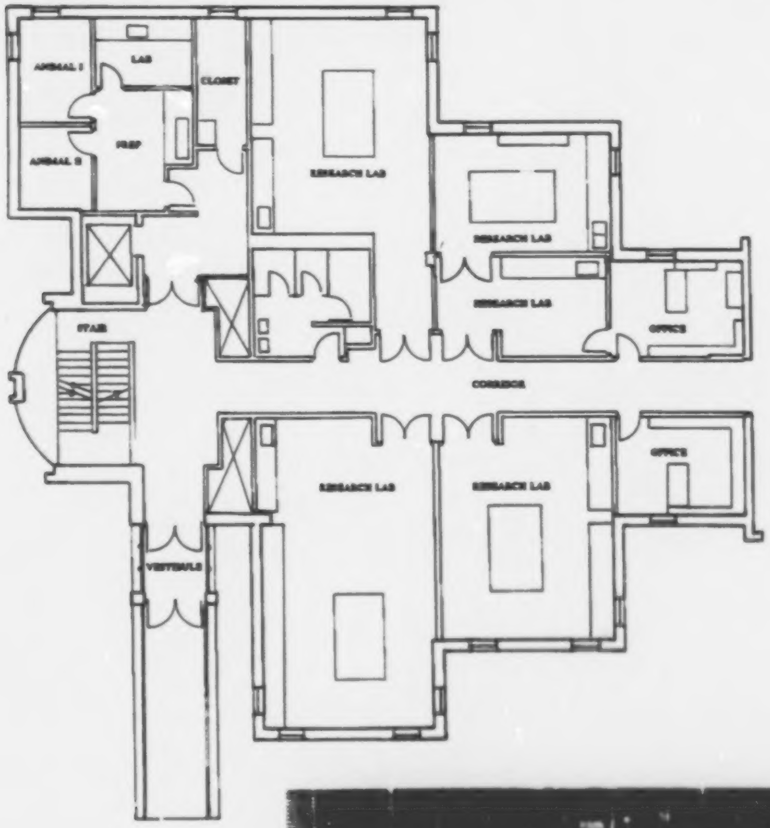
"When we started the process our facilities were limited to a few IBM and Zenith PCs in faculty offices and a small Macintosh laboratory located in a separate building," said one professor. "In order to make these sparse facilities available to students, we often had to open our offices to students during evening hours."

At first, funding for equipment and renovations was difficult to obtain, but ultimately grants from the IBM Corporation and the Sloan Foundation provided equipment and financing for the first laboratory. To keep costs to a minimum, this lab was constructed within a space already controlled by the department. The layout of the room was very simple: faculty wanted the computers on counters along the perimeter of an ordinary classroom. Later, support from NSF's instrumentation program allowed creation of a second class and lab room designed in the same way. It was in 1991 that the college redesigned and enlarged the department's space after administrators accepted the department's argument that mathematics had become a laboratory science. The renovation brought two new laboratories of workstations and PCs for student use, a redistribution of faculty offices, and additional classrooms for the department.

The new "dual-use" classroom/laboratory learning spaces, which are the core of the changes and renovations, are just that—two areas in one room. The "classroom space" has thirty desks arranged in rows facing forward as in a traditional classroom, and the "computer space" is ten computers evenly arranged on counters around the perimeter of the room. Students use the computers in teams of two or three, and face away from the central desk area when working on the keyboards.

Typically one-fourth to one-half of class time is spent in work at the computers. While it may seem counterintuitive to think that students moving themselves and their materials from one set of desks to another is an advantage to teaching, Mount Holyoke faculty defend it as a convenience. "The arrangement divides their work," said one professor who was involved in the department's planning of the new lab space. Since the students are not sitting at row after row of computer benches, facing forward, they have no divided loyalties between the two vital parts of class time—eyes don't move between instructor and computer keyboard during lectures. "There is no ambivalence between when we talk to the students and when they work on problems on the computers," said the professor. "The old way of having computers integrated into the classroom destroyed the lecture space," since it could be unclear where the students ought to focus their attention.

What are the advantages to these labs, and why is it important to integrate this focus into the classroom? "Mathematics graduates today are more empowered than the typical math major 25 or even 10 years ago," said the professor. "The computer allows a broader sense of reality for mathematics."



FIRST
FLOOR
PLAN

BEST COPY AVAILABLE

RENOVATIONS AND ADDITIONS: WEIGHING THE COSTS

The Lake Forest College Story

What is interesting about our new science building at Lake Forest College is that it evolved as a result of studying options. At first, as part of the Campus Master Plan, we planned to move the Department of Psychology from the Science Center to the newly renovated "North Gym" (the name reflects its former use). Then, or so the plan went, research laboratories for biology, chemistry, and physics would move into the spaces the psychologists had left. This plan, based on some very crude estimates, was going to cost about $500,000.

Reality set in when we realized we would need a lot of hoods, but that the machinery we had to run them would not be powerful enough. The chemists need many hoods, and in fact we joked that the number we wanted would cover the walls instead of wallpaper. Biologists also need the hoods, but not as many. When the original plan was put together, no one thought to consider how the hoods would put a strain on the HVAC system, and how the machinery could not support it.

This was only the first impediment to using the existing spaces (which were originally designed as classrooms) for the new research labs we needed. When new, more exact, estimates for the renovation were in (estimates which included changing the HVAC machinery), the project cost climbed to about $1,500,000, making the conversion price per square foot of usable space about $325.

We realized that new construction would cost less than converting existing space. Besides, the existing space could be put to good use in ways that did not require extensive changes. In any case, the space we would have gained for research according to that plan was only a band-aid—less than 5,000 square feet—not worth what we would have to pay for it. We then thought about adding an additional floor to part of the Science Center, and also considered building a small new facility. When the trustees realized that these temporary solutions would involve very high costs, they authorized further exploration of a new structure.

When finished, the new building was attached to the old science building, the Johnson Science Center, making it an extension of the original. Of course, since it is highly research-intensive, the per square foot cost was high, but it is designed to be entirely of research labs, each of which is designed for close supervision by faculty, a prime safety factor. To be sure, the ratio of what we wanted to how much money we spent to get it, is more in our favor than it would have been with mere renovation. Also, faculty offices are built into part of the bridge connecting to the older building, which allows for interaction between faculty and students; this is especially valuable when questions come up in the course of independent research.

We wanted to provide a sense of community among the students, both those involved in our research and those not majoring in science. The entrances to labs are close to each other, giving a sense that everyone is "together" in the study of science. Specifically, in the case of chemistry and physics research labs, they are very close to the places in the old building where majors tend to study and gather informally. Also, because of the traffic pattern into the building, many students pass by the research areas on their way to classes, thus we can "advertise" what doing science is about.

It took a long time to figure out what to do, but we're convinced that, considering all the options, the decisions and compromises we made were the right ones.

The College of Wooster Severance Chemistry Building

Wooster, Ohio

Architect: Payette Associates, Inc.
Boston, MA

Project Type:
Addition and Full Renovation

Size:

Gross Square Feet	
Renovation	28,000
Addition	14,000
Total Gross Square Feet	42,000
Total Net Square Feet	21,695

Area Breakdown:

Administrative Office	2,955
Lecture, Classroom	4,030
Teaching Labs	6,740
Lab Support	2,010
Independent Study	4,060
Stockroom	1,900

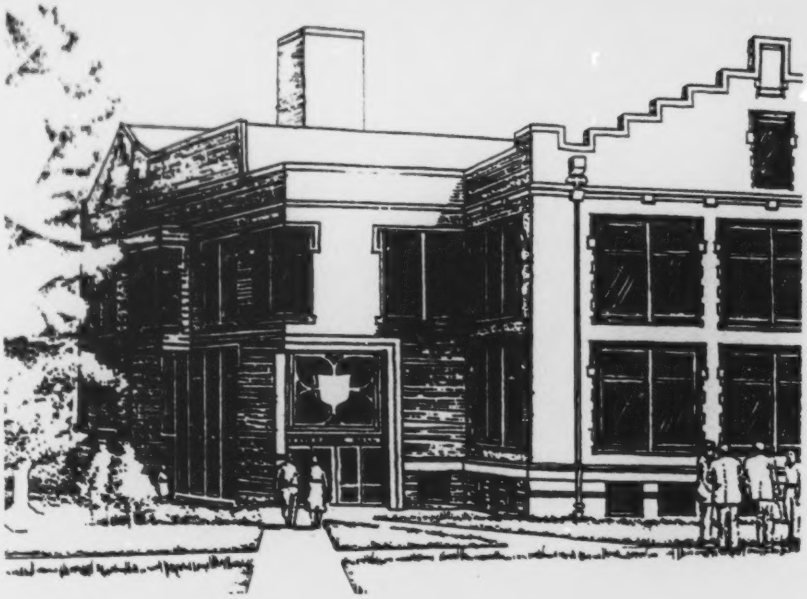
Construction Cost (Estimated):

Renovation	$4,180,350
Addition	$2,734,200
Total	$6,914,550

Completion Date:
Construction September 1997

The Severance Chemistry Building occupies a prominent site on the main axis of the College of Wooster campus. It is a turn-of-the-century structure, one of the original buildings on campus, and has a charming, dignified character. However, the building has not been renovated since the 1950's; it is in poor condition for teaching chemistry, and it is not ADA-accessible.

The option to relocate the facility was discarded because of Severance Hall's symbolic image and its key location on campus.



The new addition provides an inviting, accessible entrance to a two-story lobby which is its centerpiece.

The goal for the project is to create a state-of-the-art facility for the Department of Chemistry that will retain its prominent campus location and will enhance the student/faculty interaction which is its hallmark. The project consists of a full renovation of the 28,000 gross square feet existing building and a 14,000 gross square feet addition. The building contains undergraduate chemistry teaching labs, independent study research labs (shared by faculty), laboratory support space, classrooms, and faculty offices.

Design Approach

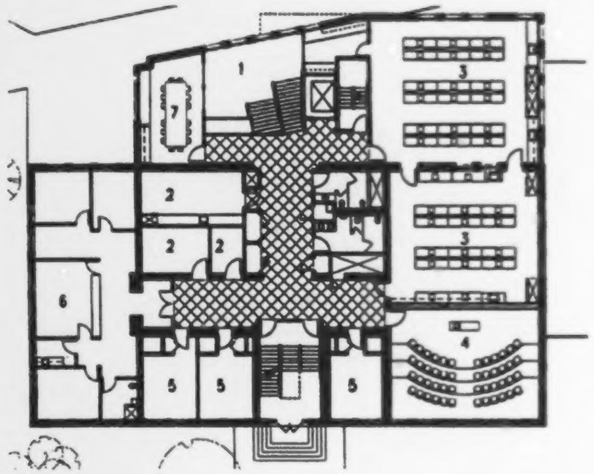
Early design studies included an option to build a new facility in a new location. This option was estimated to cost less than or equal to renovation/new construction. However, this option was discarded because of Severance Hall's symbolic image on the campus and its key location adjacent to the science library and the biology building.

The new construction incorporates the same materials as existing Severance Hall and is contextual in massing and detail to the existing Jacobean architectural character of the College of Wooster. The massing of the addition responds to existing paths and adjacent buildings and provides a welcoming front door to the campus.

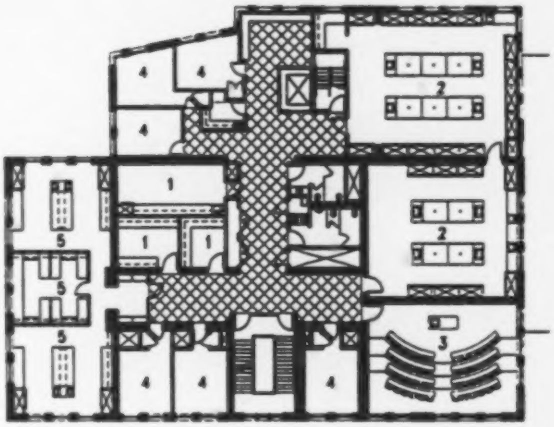
The new main entrance recognizes increased pedestrian traffic from the student center, housing, athletic facilities, and the science library; it is directly on grade and is handicapped accessible. The two-story entry lobby is the new centerpiece of the facility and includes an elevator which accesses all floors and the mechanical penthouse.

Building Organization

The addition houses the 72-seat lecture room, the 36-student general chemistry lab, and the 24-student organic teaching lab which are all spaces that cannot fit within the structural constraints of existing Severance Hall. New mechanical systems are included in the attic of the addition which backfeed the older structure through the attic. The high floor-to-floor height in Severance accommodates the new mechanical systems distribution.

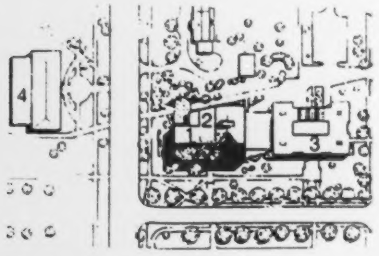


FIRST FLOOR PLAN
1. Entrance Lobby
2. Lab Support
3. Teaching Lab
4. Classroom
5. Office
6. Administration
7. Seminar



SECOND FLOOR PLAN
1. Lab Support
2. Teaching Lab
3. Classroom
4. Office
5. Independent Study

Organic Chemistry Lab



SITE PLAN
1. Severance Hall
2. New Addition
3. Biology
4. Science Library

The building is organized with a single hallway on all floors that allows frequent contact between students and faculty and provides an identity for the department; an easily accessible faculty is the heart of Wooster's chemistry education. Faculty offices are located on the first and second floor in close proximity to the teaching labs.

Each floor has a shared instrument room and X-ray, NMR, and computer graphics rooms are available as shared departmental resources.

The two general chemistry teaching labs are on the first floor next to each other with connecting doors which allow flexibility in class sizes and teaching methods. All of the labs are arranged to allow pre-lab discussions within the space with clear sight lines to the front of the room. The organic chemistry labs are arranged with six-foot chemical fume hoods around the perimeter which are shared by two students each. Instructors observe activity in the hoods from the bench area in the middle of the labs.

The organic and the inorganic labs are located on the second floor where the fume hood exhaust can be more easily routed to the mechanical penthouse above.

The ground floor accommodates a central chemical stockroom, prep lab, chemical waste area, and centralized loading and receiving which will serve both chemistry and biology buildings.

The independent study program for chemistry majors is a unique program at Wooster thus in the building are provided thirty-two spaces for Independent Study (I.S.) students which vary between analytical, physical, inorganic, and organic chemistry. Most of the I.S. space with heavy fume hood requirements is in the attic of Severance, which easily accommodates the exhaust. Eight I.S. students occupy moderate fume hood density lab space on the second floor. Faculty research takes place within these lab spaces.

The floors are organized around a single hallway which allows frequent contact between students and faculty.

Design Documents.

Developing design documents begins once the facility program and the feasibility study (if needed) is complete. This process consists of three phases: schematic design phase, the design development phase, and the phase in which the construction documents are created.

Schematic Design. Schematics give preliminary floor plans and locate the various spaces and their approximate sizes in accordance with the adjacencies you have established in defining the facility program. (You will find some adjacencies and desired shapes of rooms will fit well, while compromises will need to be made on others.) In the schematic designs, the general principles of the spaces defined in the facility program will be affirmed, including general room layout, placement of benches, and equipment in labs. Questions about flexible vs. fixed seating in the classrooms, general areas to allow students and faculty to gather, traffic patterns in and through the spaces, will also be explored.

In the schematic designs, your design professionals suggest preliminary elevations to give you a general indication of the overall size, massing volume, and preliminary design of the facades.

Issues addressed in the schematic design phase include design of:

◆ **laboratories**
  - generic lab modules vs. custom labs
  - open vs. closed labs
  - lab module layout (square foot/person: past, present, and future; bench, desk, fume hood; daylighting)
  - fixed vs. flexible casework
  - biosafety cabinets
  - lab equipment (fume hoods: past, present, and future)
  - safety

◆ **classrooms**
  - auditorium for large lectures
  - spaces for seminars, small classes
  - flexible seating; AV facilities; demonstration space

◆ **support spaces**
  - types (in-lab; dedicated; shared)
  - support/lab relationship

◆ **offices**
  - types (in-lab; shared; private)
  - office/lab relationship

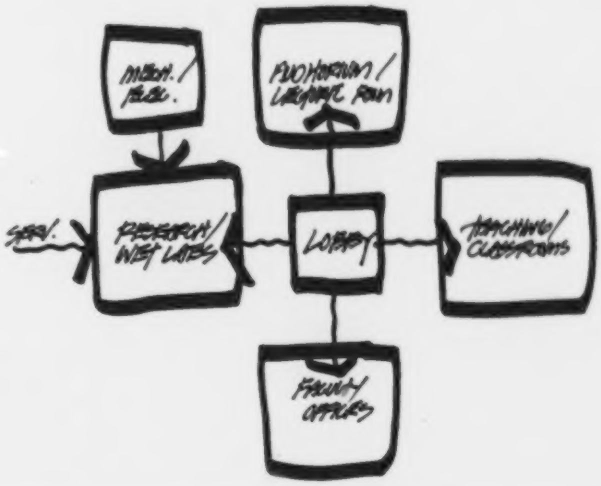
◆ **animal facilities**
  - clean/dirty corridors
  - isolation suites (transgenic; nude; SCID)
  - multiple-species animal rooms
  - quarantine rooms

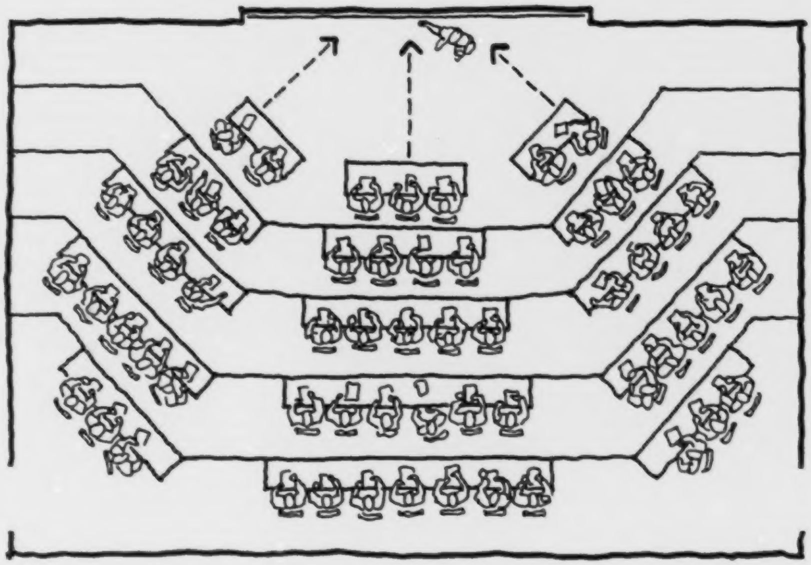
◆ **common/public spaces**
  - student gathering space
  - atriums

◆ **infrastructure**
  - systems
  - service corridors
  - interstitial space

As you study the schematic designs developed by your architects, you will gain a sense of the organizational development of spaces on each floor, the relationship of faculty offices to teaching labs and other teaching spaces, and to faculty and student research facilities. Think about how the configuration and arrangement affect the desired character of the teaching, learning, and research that has been defined in the facility program.

The schematics also articulate the general approach to mechanical systems design and for other services to be provided (for example, electrical and piped services), as well as their general locations. Locations for services will be specified during the final development of the designs.



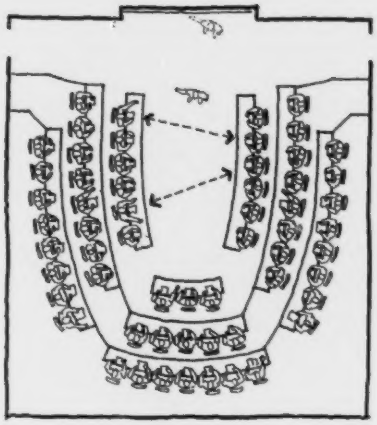


Being able to localize the mechanical, electrical, and plumbing services can be a cost-benefit, but you should consider both benefits and drawbacks to such groupings. Such an arrangement may isolate faculty offices, lounges, and other nonlab areas to other parts of the floor and/or building and thus fail to nurture the desired interactions. On the other hand, grouping faculty offices and lounges together can increase interaction between faculty, and offer students easy access to many faculty members. Other groupings might be to locate faculty offices and research spaces near the appropriate teaching laboratories, and perhaps next to the student research facilities.

In addition to considering such adjacencies, you should study how the elements *within* each space fit together, and how they might affect desired interactions. For example:

◆ There are various ways lecture halls can be arranged: at one end of the spectrum is the typical arrangement, which provides fixed seating with tablet arms in a tiered arrangement. The nonmovable, forward-facing seats direct the students' attention toward the front. This design is conducive to audio-visual presentations and lectures, not for collaborative activity.

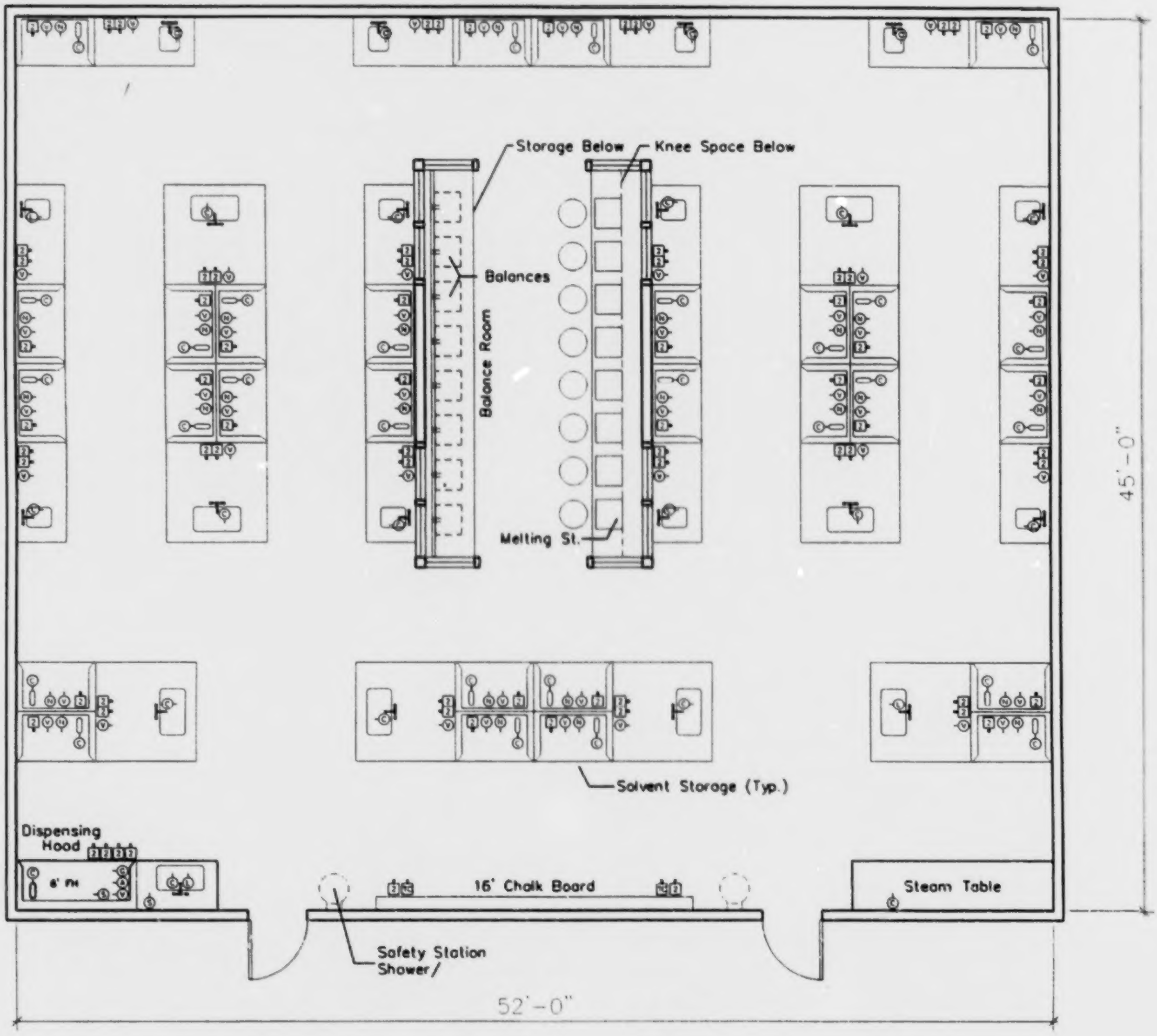
◆ A lecture hall that is supportive of hands-on, collaborative activity might include an arrangement of seats that tilt and swivel behind counter-type tables arranged in a deep "U." Space behind each seat allows students to walk to other areas in the room, and to face each other and engage in productive discussions. The counter-type tables also provide sufficient space for laptop computers and other resource materials.



Another example:

◆ Teaching labs can be organized to support a variety of styles of teaching and learning. A general introductory chemistry course usually occupies laboratories organized with long rows of laboratory benches. Fume hoods and other laboratory equipment and instrumentation located at the perimeter of the laboratories allow for the efficient sharing of these facilities, without promoting "ownership" of the elements. (See Part Three, for discussion of laboratory design.)

◆ Teaching laboratories organized as a series of smaller workstations, each with its own lab bench and sink, and perhaps shared fume hood, in contrast, provide a student with a semblance of the elements and configuration of a research environment.



Schematic Design
Organic Chemistry Laboratory

FACILITY NO. : 1.213
NAME : Organic Chem Lab Chemistry

AREA (NSF) : 2,340
DATE : 27 September 1995
NUMBER REQUIRED : 1
REVISIONS :
TOTAL AREA (NSF) : 2,340

PURPOSE/ACTIVITY : Organic chemistry teaching lab, students work individually or in pairs
OCCUPANT : 24 - 28 students per section
ADJACENCIES : Stockroom, balance room, instrument room

FLOORS : Epoxy
WALLS : GWB, painted and glazed at balance room
CEILINGS : Exposed, painted
CEILING HEIGHTS : NSR
DOORS : 3'-0" wide, wood
WINDOWS : Desireable
ACOUSTICS : Partitions rated for STC45
MISC. SPECIALTIES : Marker/chalk board
CONTRACT FURN./EQUIP. : Benches, counters, fumehoods, steam table, balances, melting pt. apparatus
NON-CONTRACT FURN./EQUIP. :

HVAC :

ELECTRICAL :
- RECEPTACLES (120V) : 2 duplex plus 2 @ ea. bench
- LIGHTING : 70 - 100 fc
- SPECIAL POWER : NR
- EMERGENCY POWER : NR
- FUME HOOD OUTLETS : per diagram

PLUMBING :
- SINKS : 21 per diagram
- CUPSINKS : 1 @ ea. fume hood
- LAB GRADE WATER : 1 outlet @ ea. sink on shared bench
- SPECIAL GASSES : Steam at shared hood
- COLD WATER : 1 outlet @ ea. sink or cupsink
- PROCESS WATER : NR
- AIR : NR
- GAS : 1 outlet @ ea. fume hood
- VACUUM : 1 outlet @ ea. fume hood and shared bench

SAFETY REQUIREMENTS :
- EYEWASH : 2 with shower
- EMERGENCY SHOWER : 2 per diagram

COMMUNICATONS :
- TELEPHONE/COMPUTER : 2 outlets

SPECIAL REQUIREMENTS :

Design Criteria Sheet
Organic Chemistry Laboratory

Each of the four categories of design criteria [for classroom design] should satisfy the following four design requirements.

FUNCTION. The classroom must be able to function effectively for the type of instruction to be carried out within its walls. A classroom used to teach physics needs to accommodate live demonstrations whereas a classroom used for music performance must have a completely different set of criteria.

FOCUS. The room should focus the student's attention on the instructor, screen, and presentation area. Focus is achieved through an arrangement of architectural elements, proper acoustics and lighting, and the absence of visual distractions.

FLEXIBILITY. Because many classrooms have multiple uses, they must be flexible enough to make 20 students—or 50—comfortable in the same room. And most classrooms need to permit lectures as well as slide presentations with note taking.

AESTHETICS. Attention to aesthetics allows students to enjoy their classroom encounters, and feel like learning. Attractive classrooms lend dignity to the learning process, and announce silently that the cultivation of the mind is a beautiful and dramatic activity. Mean and dingy classrooms—especially if the athletic facilities and art center are handsome—suggest that classroom teaching is a lesser enterprise. Attention to form, line, color, texture, and variety can be achieved at relatively little additional cost and a tremendous return on the investment.

—*Michael Owu, "Classrooms for the 21st Century," Planning for Higher Education, Volume 20, Spring 1992.*

As you study the schematics, think about how spaces without access to views and daylight would influence people using them. Lecture halls, equipment rooms, and other support spaces that are not occupied for long periods are better candidates for interior zones. Offices, research labs, and teaching spaces are most successful when exterior windows or even interior corridor windows are provided, as they then encourage extended use.

Take care also that furniture and equipment can be arranged properly, particularly fume hoods and other large laboratory equipment, so that they do not impede your ability to monitor student work. As it gives students the opportunity to "do science," and more closely resembles a research environment, the right organization of space helps promote student interest in science and mathematics.

During the schematic design phase, and later with detailed drawings, faculty members and all other building users must continue to be involved. Having a set of the latest drawings on public display, where they can be marked on or "plastered" with stick-on memos giving suggestions or objections, is a good way to keep the community informed. The project shepherd and project manager should have a formal mechanism to gain reactions regularly from all members of the community.

Comments on the drawings should be documented in the form of memos, and the project team should be required to respond to each comment (even if the suggested change is not possible or wise). The project shepherd, project manager, and project team need to be vigilant in assessing the comments and incorporating them into the design. Assign one or more faculty or staff members with responsibility for a particular room, to monitor plans and changes. They must also sign off on the final schematic designs, indicating their approval; this will impart a sense of responsibility, and minimize the chance that changes will be requested later.

Throughout this phase, the architect discusses the design approach and alternatives with the project shepherd and project manager, the project team, and the executive committee. Your design professional might come to campus for a week and spend long days in intensive discussions about options. At some phase, a mock-up of a potential lab module or a virtual lab environment might be constructed to give faculty and students a sense of how the space might work. This approach can be particularly valuable when you are trying to determine how to use new technologies most efficiently and productively in the new spaces.

At this point, there are many more details to be established. A preliminary cost estimate is prepared based on the drawing and outline specifications prepared by the architect and engineers. The schematic design cost estimate should be considered a preliminary estimate. This usually includes a design contingency to reflect the preliminary nature of the documentation. The architect also works with the consulting engineers to develop the initial engineering design concepts. During this phase, the project team is involved in reviewing progress submissions prepared by the architect and the consulting engineers and provides additional information, as required, concerning the developing design concepts.

◆

Having a set of the latest drawings on public display, where they can be marked on or "plastered" with stick-on memos giving suggestions or objections is a good way to keep the community informed.

◆

Taking care to examine and understand the schematic designs is a critical step in the process, one which requires the aggressive leadership of the project shepherd and project manager. It also requires the careful attention of all building users. This is when you begin to see how you might actually function in the spaces, when visions and dreams become more realistic. It is also when the facility program gets translated into footage, and when more accurate cost estimates can be projected.

The results of the schematic design phase are a set of design drawings, specifications outline, and a cost-estimate. These must be approved by the faculty, project team, and executive committee before the project moves into the design development phase.

Design Development.

Following the approval of the schematic designs, the architect moves into the design development phase, in which the spaces and structures are designed in detail, including detailed drawings of elevations, floor plans, site plans, sections which illustrate the comprehensive design of the project. Design development addresses the detailed design of each room, including the selection and location of furnishings and casework, location of electrical and piped services, choice and location of lighting, choice of colors and finishes, and other details. Paint, colors, carpet patterns, and other interior design elements are often discussed and established during this phase, as are bricks, colors, roof materials, and window configurations.

It is at this time that the architect and the engineers develop in greater detail the project specifications and a cost estimate. Although the project design has been established by this time, the preparation of construction documents has yet to be completed, and therefore cost estimates finished by this phase include a contingency for construction details that will be created in the following phase. (See Chapter IX for discussion of project budget.)

This is a critical time for the project shepherd and project manager as they must get faculty attention to check the design drawings very carefully. (Only a user knows that instruments come with three-foot cords!)

The architect will submit regular progress updates to the project team and executive committee, and work closely with the project shepherd and project manager throughout the process. At the end of the design development phase, faculty and staff with responsibilities for a particular space must *"sign-off"* as they did at the end of the schematic design phase.

The final products of the design development phase are the detailed design drawings, draft specifications, and cost estimates.

Flexibility. Decisions about flexibility and convertability will be refined in the design development phase. In planning and designing new spaces, you must recognize that over the life of the building changes will occur in curricula, technology, student interests and enrollments, as well as in the disciplines. A building should be designed to accommodate change as easily as possible, within the limitations of the facility program, budget, and other demands on the design. This means the building should be "flexible" and "changeable." Flexibility is the ability to accommodate change without moving partitions; changeability is the ability to accommodate changes by moving partitions and reorganizing interior space.

A flexible building or space will permit relatively near-term changes such as reconfiguring benchwork, changing the use of a laboratory for a new faculty member, adding instrumentation, updating classrooms with AV systems, and perhaps even converting an office to a lab or lab to an office.

Flexibility is highly dependent on the capacities of the building systems, so planning for flexibility should include some spare capacity within the constraints of the budget. The electrical service should be able to serve the demands that will grow with instrumentation, equipment, and electronic systems. Some spare capacity in the HVAC system is desirable to serve the heat loads that go along with increases in electrical demand as well as fume hoods that may be added in the future. Where spare capacity is uneconomical, the same benefit can be provided by reserving space for the mechanical equipment to be added as loads increase. Likewise, extra space in mechanical shafts will contribute to flexibility by permitting the addition of ductwork as hoods are added and heat loads change.

◆

A building should be designed to accommodate change as easily as possible, within the limitations of the facility program, budget, and other demands on the design.

◆

While flexibility in a building allows near-term adaptations, it is changeability that allows longer-term revisions. A building that is changeable is one that minimizes the cost and inconvenience of reconfiguring interior space and relocating partitions. Such reconfiguration may be needed to allocate space to research or instrumentation, or to otherwise adapt to emerging technologies or changing pedagogical approaches during the life of the building.

If flexibility depends upon the capacity of building systems, changeability depends on the organization and location of the elements of those building systems. Some building elements are fixed or very expensive to move, including columns, stairs, elevators, mechanical shafts and equipment spaces. Corridors are also usually fixed. How these fixed elements are located will determine how easily a building can be reconfigured in future years by moving partitions.

There are also operable and movable partition systems that offer a more direct approach to reconfiguring space. In teaching spaces, operable partitions may have application in subdividing a seminar or conference room. Movable partitions can be relocated, but their cost usually limits their uses.

Both flexibility and changeability reflect the building's possibility for change; they do not provide for growth. The ability to make a lab larger by moving a partition is useful only if the space on the other side can be made (and used) smaller. Growth goes hand in hand with change. To accommodate growth, a building should be planned with a loose fit. Providing storage space, extra conference rooms, or other "soft" space will make a building amenable to change over the years.

Modular Planning. The concept of modular planning is often utilized by design professionals as a means of accommodating certain flexibility goals by organizing building components and allocating space within a building on a modular basis.

The planning module is the fundamental increment of space, and establishes a grid by which building partitions, doors, windows, structural columns, and other building system components are located. Modules may be combined to produce large, open laboratories or subdivided for small, special purpose support spaces.

The size of the module is generally based on the depth of laboratory benches, hoods and/or equipment space on each side of an appropriate aisle space. Assuming a 6'-0" wide aisle, which is typically considered appropriate for back-to-back work space, passage of laboratory carts, and wheelchair accessibility, the overall width of the planning module tends to range between 10'-6" and 12'0".

The depth of the planning module is highly variable, and may be derived by analyzing the bench, hood and equipment space required for student workstations, laboratory instruments and research procedures. Issues which may impact the module depth include preferences for island vs. peninsula benches, the desired clustering of students in teaching laboratories, and the locations and quantity of fume hoods, sinks and technician desks. Typical module depths range from 24'-0" to 36'-0". Shorter module depths tend to restrict space planning/layout options, while greater depths may result in structural spans too long to resist vibration effectively and economically while maintaining a column-free laboratory environment.

Modular planning applies not only to the architectural, structural and laboratory casework systems, but to the HVAC, plumbing and electrical systems as well. The goal should be to distribute these systems in a modular, repetitive, consistent manner, allowing ease of maintenance and adaptability for changes in the future. The systems should be zoned with branches to each space allowing changes to, or retrofit of, any laboratory unit without disruption to adjacent spaces.

Construction Documents.

Following the approval of the design development phase by the project team and executive committee, the architect and engineers complete construction documents. As these are completed, the architect and engineers will present two or three progress submissions for review and approval. The building will be constructed according to these drawings.

Construction documents include detailed specifications describing all materials, quality of the construction, samples, and testing requirements. Prior to engaging a contractor, the final cost estimate can be prepared to confirm that the project budget has been maintained.

In this phase of design development, the architects and engineers convert the designs into something on which contractors can bid and build. Where pipes need to be run and what size the pipes need to be are determined in construction documents. They will also describe the structural part of the building and detail how walls are to be built.

In the construction document phase, the drawings become increasingly difficult for faculty and staff to read. No longer will all the details of a single room be on one page, but the structure, casework, plumbing, and electrical services will be on different pages.

It is at this time that faculty must be absolutely sure that the utility arrangements, the layout of laboratories, and the furniture design they requested in the design development are reflected properly and will meet the needs of the program defined for the space. It means being sure that the area has adequate wiring for computerization, and that HVAC and lighting needs are addressed in detail.

Ideally the designs from the design development phase will be unchanged in construction documents, but often in the process, conflicts with structure, piping or ductwork arise and compromises are necessary. It is critically important that building users are aware of these conflicts and participate in making decisions about changes.

After this point, changes will be costly. This is also the time to be sure that the finished product will be in accord with safety and environmental codes and with legislation regarding accessibility.

The project shepherd must continue to serve in the ongoing role of protector of the facility program and guard against seemingly innocuous physical changes that in time would have serious impact on the teaching and learning that is to be carried out in the space.

Conclusion. The phases of planning as outlined in this chapter are not arbitrary; there are real differences in what is to be accomplished in each phase. Just as it is critical to plan a route for a trip before driving the car out of the driveway, it is critically important to complete each phase, and have all parties agree to the result before beginning the next phase. If the program states that the introductory biology lab should accommodate 24 students, the schematic design should provide such a facility. If, however, after schematics are completed, the institution decides the lab must serve 30 students, a major problem ensues. If that room needs to get bigger, which of its neighbors will get smaller? In addition, all the time spent earlier designing that space is lost. Similarly, if a design of an organic chemistry lab is agreed to in schematics, but plans change after design development is completed, a costly redesign of all electrical systems, piped systems, and HVAC systems may be required. Such changes are bound to delay the project, and may add substantially to design costs.

The amount of time and expense for design required for a project varies substantially with the size and complexity of the project, the schedule of the users, and designers, and the urgency for completion of design. A rough estimate of the time required and fees associated with each phase of design and construction is:

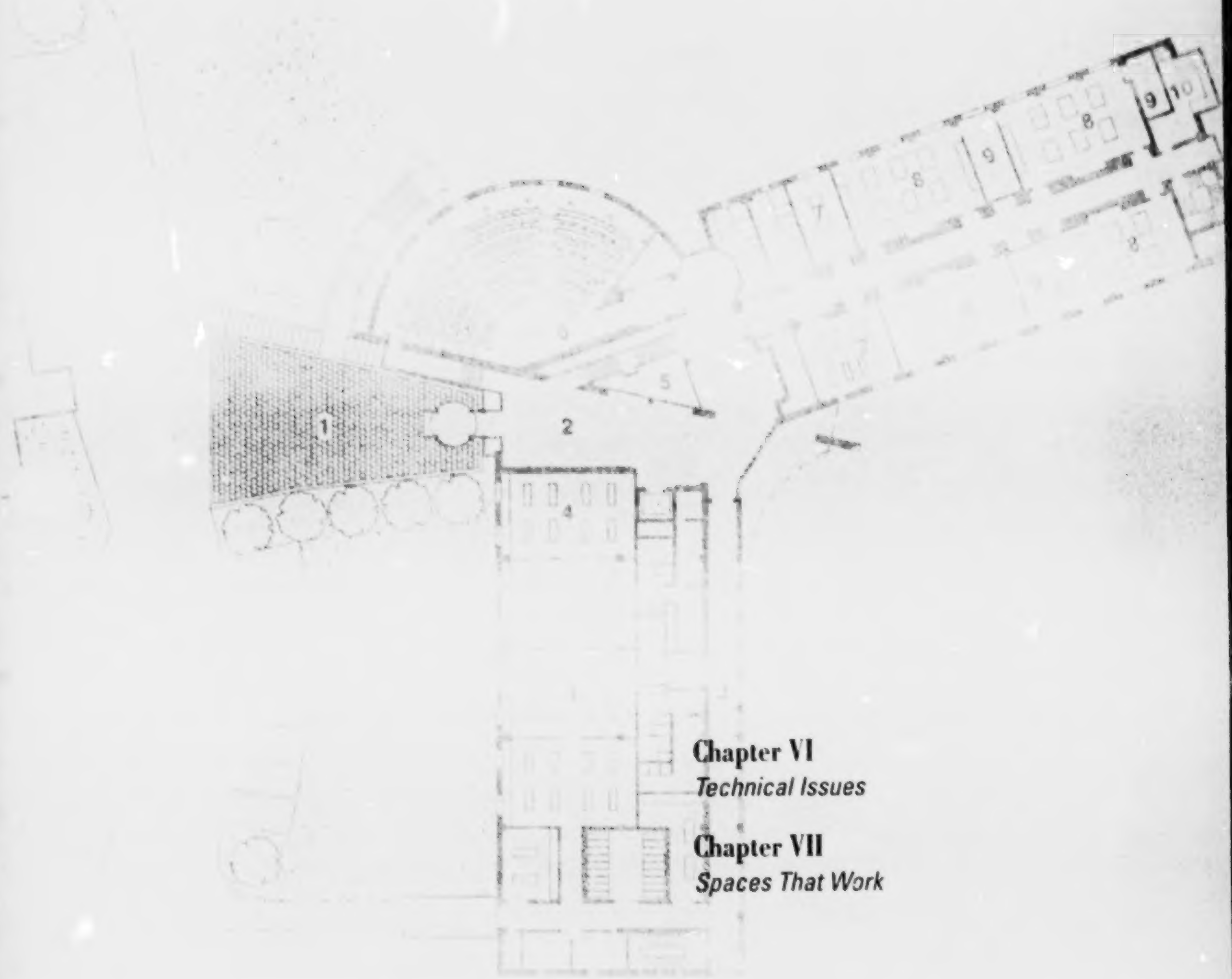
Schematic design:	15 percent
Design development:	20 percent
Construction documents:	40 percent
Bidding:	5 percent
Construction administration:	20 percent

After your design team is hired, a tentative schedule will be established. Be sure to build into that schedule adequate time for the faculty and other users to review the drawings, compile comments, and get responses from the design team. Be careful to note how this schedule fits into the rhythm of your academic year (it may not be easy to get faculty to review the drawings carefully during the week of finals). Depending upon the local culture, breaks in the academic calendar may be a very good or a terrible time to have intensive sessions with members of the project committees and design team.

The planning process is like a research project. You must start with a general sense of direction, but be prepared for possibilities and pitfalls along the way. As the designs evolve, you will veer from your preconceived path (if you had one), pursue some side paths (some of which may be productive and others not), and end up in an exciting place. The planning process is dynamic and invigorating; it will involve many people, requiring them to revisit assumptions and ideas about teaching and about doing science. It is critically important to have stamina, optimism, and a sense of humor—and to celebrate progress at regular intervals along the way.

PART THREE

SPACES THAT WORK



Chapter VI
Technical Issues

Chapter VII
Spaces That Work

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PART THREE

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Here we present examples of spaces that work from both the technical and the educational perspective. Facilities that support research and teaching in the sciences are among the most complicated building types. This complexity reflects, in part, the many different kinds of spaces therein: labs for teaching and research, offices for faculty and staff—and perhaps students, stockrooms, equipment rooms and animal rooms, greenhouses and tissue culture rooms. Each of these spaces has unique requirements in regard to size, shape and adjacencies. The complexity of science facilities is also the product of the density and sophistication of equipment systems and services needed for the infrastructure of the building, as well as a result of the increasing codes and regulations that must be addressed. The complexity is greatly increased by the need to provide graceful flexibility so that the spaces can change to accommodate new ways of learning, new technologies, and new directions in science and technology.

A lab designer suggests that in the selecting and assembling of the HVAC systems for science facilities, decisions should be made about each individual piece based on *how it will serve its assigned purpose* over the life of the system and *how it makes the system work*. This advice for the process of developing building systems holds as well for the process of deciding how individual offices, classrooms, laboratories, and community spaces will serve their assigned purpose and how they make the system work in a way appropriate for your students and faculty, your departments and disciplines. An aim should be spaces and structures that are *works of art* in the sense that they "possess some measure of inner unity and coherence," that each space serves its particular purpose well, and contributes to the value of the entire building.

As you review the stories and case studies presented throughout *Structures for Science*, consider how scientists work, how they come to understand and interpret our world. In *PKAL Volume I*, we talk about the ideals on which the scientific community rests: honesty, impartiality, and openness. As your building reflects those same ideals, providing safe and flexible spaces to do *science as scientists do science*, in formal settings and in the serendipitous and unexpected teachable moment, your spaces will work well.

CHAPTER VI: TECHNICAL ISSUES

Introduction.

Modern academic facilities for teaching science and mathematics have become very different places when compared to spaces designed and built even as recently as twenty years ago. Emerging technologies, concerns about safety, accessibility, and environmental issues are now significant factors in determining the character and infrastructure of buildings for undergraduate programs in these fields. Today's buildings and those of tomorrow must provide services that accommodate sophisticated communications networks, in addition to services for air-conditioning, power distribution, and water piping systems; they must reflect prudent practices about safety and about environmental concerns both internal and external to the facility. Contemporary structures for science must also have an infrastructure that is efficient in terms of initial cost, in cost for maintenance and energy use over the life of the building, and flexible enough to accommodate changes in program and use in the years ahead.

In this chapter, the infrastructure and technical issues that must be considered in your planning are addressed. These issues are complicated, and persons with specific expertise and experience should be engaged to give advice and counsel as you proceed. Your project manager is the key person here, working with the lab designer, special consultants and engineers (and faculty and institutional budget officers), to ensure that all deliberations and decisions in regard to such issues are well informed.

Your aim is a building in which the individual systems work together to provide an environment for students and faculty that is functional, cost-effective, comfortable, engaging—and safe.

HVAC Systems.

Heating/ventilation/air-conditioning (HVAC) systems circulate and exhaust conditioned air at a prescribed rate of exchange. The basic system is comprised of fans, filters, air handlers, heat transfer coils, control valves, and duct work. The fans either draw air in, recirculate, or blow air out of the building via systems of ducts.

Your primary concern in developing the HVAC system for your building should be that the distribution of air within the building takes place in a manner that ensures the safety, health, and comfort of all students and faculty. Your secondary concern is that your facilities perform to a high standard of efficiency.

Think about what works and what does not work in your present facility, as documented in the predesign stage. Is remodeling not an option because the service chases are too small, impossible to alter or expand? Do vertical structures and/or the placement of service shafts reduce options for refiguring space? Are air handling problems difficult to remedy because of inaccessibility of utility systems? How does your current HVAC system promote or inhibit the kind of environment for learning that you desire?

> Basic research is not, of course, confined to the activity of scientists. Basic research—that is, investigation that seeks new knowledge and understanding rather than solutions to immediate problems—is the essential nature of research on the part of all scholars. It obviously includes but is not restricted to basic research in the biological, medical, physical, and many social sciences. In the sciences, however, there is a particular style to the enterprise. Teaching in these areas—done in laboratories, in groups or teams, through colloquia, on field trips; with undergraduate, graduate, and postdoctoral students; with assistants and associates in research—is intimately and inextricably connected to research. In science, teaching and research not only go hand in hand but are often the same hand: the pedagogical act an act of investigation, the investigatory act shared with students and associates who are also colleagues, the whole a splendid, ongoing instance of intellectual and human collaboration. Of course, scientists also work alone. Not all that is done is the result of a group effort; and not everything that is done occurs in a unified act that is both pedagogical and investigatory. But the distinctive style of scientific investigation is collaborative, and the distinctive process is such that it is impossible finally to distinguish research from teaching, seeking from sharing.
>
> —*A. Bartlett Giamatti, A Free and Ordered Space.*

In thinking through HVAC systems, your concern for safety focuses first on the need for pressurization between laboratories and nonlaboratories. Such pressurization will require both a controllable air ventilation system/air-conditioning system and totally enclosed facades. To establish the flow of air that is needed, in defining the program you will have identified the specific temperatures and conditions required for each space, including heat output (BTUs) for all equipment, and pressure relative to adjacent spaces (for example, an office adjacent to a lab should have air-out-flow from the office into the lab). The amount of outside air needed will be determined both by the number of people to be occupying the space and the special exhaust requirements for the work to be done. The total volume of air supply will be based on the *worst-case condition* for laboratory space-cooling requirements, fume hood exhaust requirements, or minimum air changes for flushing of contaminates.

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It is critical to integrate adaptable building systems into your building program.

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Do not forget that the structures and spaces you are now planning need to be functional and safe for at least thirty years; thus, as metioned above, it is critical to integrate adaptable building systems into your building program. For example, a manifolded exhaust system allows for the dilution of exhaust contaminated with chemicals, safe flexible operations, and provides enhanced adaptability. In planning your HVAC systems, the need to predict unforeseen uses of the building, which may require changes in the building infrastructure, cannot be overestimated.

Floor space for the mechanical systems can be found either within the building, on the building roof, or in close vicinity to the structure. The location of such equipment depends on the type, siting, and programmatic circumstances of your project. (Remember that the location will also have an impact on the project budget.)

Plumbing systems both supply and discharge fluids and gases used in cleaning, sanitation, and experiments. Typical systems include hot and cold water, gases, compressed air, vacuum, and deionized or distilled water. Special gases can be distributed through central systems or supplied locally from tanks or stills.

Fire protection systems, typically located within the ceiling, serve to alert occupants and the local fire department of an emergency, and to extinguish a fire directly by means of heat-sensitive water sprinklers in each occupied room and corridor.

Consider:

- **air handling units.** Locate air handling units close to a "clean" outside air source. Air handling units take up a large amount of floor space, usually between 3-5 percent of the gross floor area, and are often housed on the roof, provided they are weather-proofed and reentrainment of exhaust fumes is avoided. These need to be situated so that noise and vibrations are minimal, and that they do not interfere with internal work areas (otherwise internal spaces may be unusable).

- **exhaust fans.** Locate exhaust fans at the highest point of the building, preferably on the roof center. The design of the exhaust stacks, and the discharge velocity requires careful consideration to meet code requirements. Manifolded exhaust systems are becoming more common; the plenums for these systems also require significant space. For exhaust fans, anticipate using about 1-3 percent of the gross roof area, again depending on the size and the complexity of your project.

- **cooling and heating equipment.** Requirements for cooling and heating equipment range from a stand-alone chiller and boiler plant to connections to your campus central plant system. Chilling and boiler equipment, besides adding cost to the project budget, will use approximately 3-5 percent of the gross floor area. The most appropriate location for water-cooled chillers is on-grade, with the cooling towers located either on the roof or on-grade outside the building. In determining where to place the chillers, remember to think about noise and vibration. In some cases, alternative systems such as air-cooled chillers located either on the roof or on-grade should be considered.

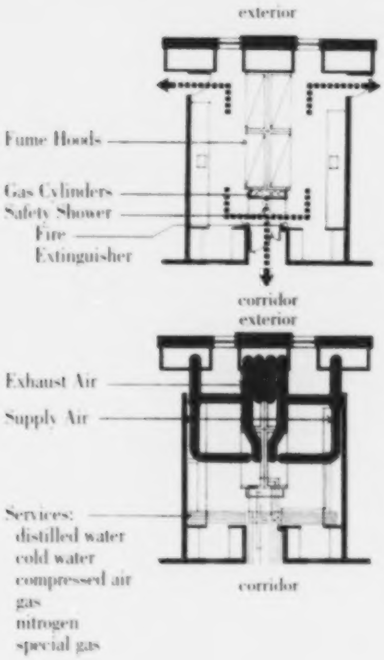
- **plumbing equipment rooms.** The rooms for your plumbing equipment should be centrally located to the laboratories (either in basement or on-grade rooms), thus minimizing distribution piping. Depending on the intensity of services required, these spaces will use between 2-4 percent of the gross floor area.

- **electrical and telecommunications distribution rooms.** These electrical and telecommunication distribution rooms should be located as close as possible to the utility company connection, but also close to the building distribution risers. It is common to have several communication closets spread throughout the building. Space requirements for these distribution rooms is usually between 2-4 percent of the gross floor area.

- **emergency generators.** The most suitable location for an emergency generator is outside the building (if aesthetics are not an issue), thus resolving the issues of noise and vibration control, fuel storage, fire and safety implications, and exhaust discharge. If you install the emergency generators inside, these issues must be addressed. Depending on the amount of emergency power required, space requirements are usually between 2-3 percent of gross floor space.

In considering options for the location of the HVAC systems, you will begin to understand the relationship between net and gross space in the building you are planning. These relationships will have a significant effect on the construction budget for your project.

Synthetic Chemistry Lab



The laboratory is arranged in wet and dry zones for four researchers performing chemical synthesis work. The dry area consists of a desk area. The wet area is arranged into four workstations, each having access to fixed equipment and services. Each workstation includes one fume hood.

—Facilities Handbook, NSF

Ductwork and Piping Distribution Systems. All laboratory facilities require a variety of piped services. This will undoubtedly include hot and cold water, and may include a variety of other services including purified water, compressed air, vacuum, natural gas, nitrogen (or other specialty gases), and steam. Depending on the water use and building codes, there may be a need for separable and industrial water systems (or the use of vacuum breakers). Drain lines from many areas will need to be made of materials to handle acids.

If many rooms require purified water (from a deionizing system or still), it is likely best to provide a central system with distribution to those rooms, but if a small amount of purified water is required in only a few locations, it may be more economical to purify it in those rooms, and avoid the cost of a distribution system. Similar arguments can be made for compressed air and vacuum. If nitrogen is used in a variety of locations, it can be centrally supplied, rather than cluttering the rooms with gas cylinders and having students handle gas cylinders. A downside of a central system, however, is that one careless user can leave a valve open and drain the entire system. Steam is occasionally used in chemistry labs for heating, and commonly used for autoclaves. Local steam generators can be purchased if a central system is not available or not economical.

The distribution of ductwork and piping throughout the building is a function of the size of the floor plate, the number of floors, the location of the mechanical rooms, as well as the need for your building to be flexible and adaptable. Architectural and programming requirements will shape how your system is established. How you wish your offices and teaching and research labs to be related may determine (or be determined by) how services are to be provided, particularly services for hood exhaust. Decisions about vertical or horizontal integration of departments in the building, which departments are to be accommodated, connected, or eliminated from the new spaces are all significant in determining how your HVAC system is to be established. The equipment (and its location) should permit as much flexibility, changeability, and expandability as possible. If your budget constraints dictate minimal space capacity, allow space for future expansion of the system as you are planning and building now.

Duct risers can require between 1-4 percent of the gross floor area. Careful coordination is required in the organization of the duct risers; the greater the number of risers tends to reduce the amount of horizontal distribution, and thus reduce floor-to-floor heights. However, increased numbers of vertical risers can reduce flexibility of space arrangements by adding fixed elements in the floor plate. Ease of access to ductwork and pipeline equipment is important for testing and commissioning, for maintenance and replacement, and for changeability; these needs also affect the location of the equipment and the type of ceiling that you select.

Size and organization of ductwork can affect the noise generated by the HVAC system. Oversized ducts with minimal bends typically provide the most acceptable levels.

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Be certain, as you select your HVAC equipment, that *each individual piece* gives value for money; consider also the *system*, how the pieces will work together.

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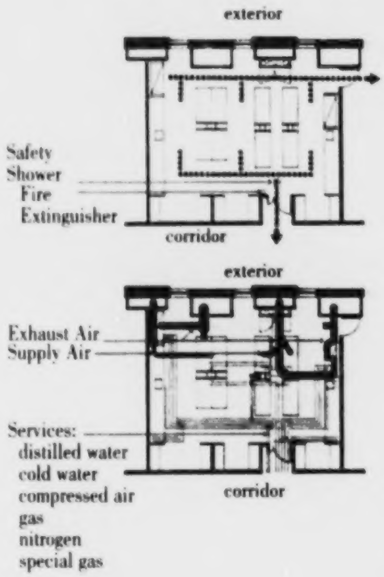
Be certain, as you select your HVAC equipment, that *each individual piece* gives value for money; consider also the *system*, how the pieces will work together. For example, an air handling unit with high noise levels might require the addition of sound attenuators to ensure that space noise criteria are met in individual rooms. By selecting a higher grade unit which has a lower sound level, you might avoid the need for sound attenuators.

The selection of equipment will also affect space in other ways. The more expensive, custom-built air handling units can take up less floor space than the "off-the-shelf" units; they will thus have an impact on meeting the net-to-gross floor area ratios you have established.

Ease of access for maintenance, and maintenance and operating costs are both important to consider. One question to ask in the selection of equipment and systems is *"Do we have competent maintenance personnel available to us?"* In this time of efficiency and cutbacks on campuses nationwide, take care to select equipment and systems that have high reliability, with low maintenance requirements. Those who will be responsible for maintaining them must have an appropriate comfort level in doing so. By selecting variable speed drives and energy efficient motors, energy saving systems will minimize energy costs. (This may allow transfer of funds to general maintenance, or to other needs for the programs to be housed in the new spaces.)

Three Module Analytical/ Physical Chemistry Lab



The laboratory is arranged in a wet and dry zone for six researchers performing analytical and physical chemical research. The dry zone consists of a desk area (study carrels) and the wet area includes experiment work surfaces and fume hoods.

—Facilities Handbook, NSF.

The Engineer's Perspective

Ask what good engineering means in a science facility and you'll get varied answers. For the user—safety, comfort, environmental control and maximizing the building's net-to-gross ratio is important. For the financial officer—budget and schedule are important. For the physical plant staff—energy, operation and maintenance immediately come to mind. Everyone just wants an engineering system that works in providing a safe environment for faculty and students, but meeting all of these objectives is not an easy task.

The key is to establish a process which integrates the mechanical/electrical design into the building fabric at the concept phase, and to establish "guiding principles" that set priorities for the various and often conflicting needs of the project, and then guide the decisions throughout the project. Engineering systems will be successful if they are integrated into the project, and are not just an "add-on" to the architectural concept. Engineering systems will also be successful if they are used right, thus educating the "users" is part of the process. For example, ideally, a variable air volume (VAV) hood system saves substantial energy costs—provided the sash is closed. Here is the catch! Will the hood sash be consistently closed in the academic environment? If not, there are no energy savings. In fact, there can be unnecessary expense, since sophisticated hood control strategies can be very costly.

In a facility for undergraduate science programs, the mechanical/electrical construction cost can run between 35-50 percent of the construction budget. Square footage for mechanical/electrical systems can run 10-20 percent of the building gross. (Remember in intense wet labs floor-to-floor heights will push 16 feet!) Even with an efficient design, energy may be consumed at a rate five to ten times that of an academic classroom facility, thus yearly maintenance costs, due to the sheer quantity of engineered systems alone, is a multiplied factor.

At Bucknell University's Science Center, the guiding principle was clear—keep it simple. The design strategy went back to basics: balancing low initial costs and efficient use with designing systems that were easy to maintain. The goals are compatible with, and not at the expense of, the academic program. What it took at Bucknell was to analyze the individual components of the HVAC system and assign the most appropriate technology to each. This approach resulted in a hybrid system tailored specifically to meet the needs identified by the Bucknell community.

The system includes:

◆ **fume hood control.** One of the "hottest" topics in lab design today is the use of a variable air volume hood exhaust system (VAV), a sophisticated control system which automatically modifies air volume in an infinite variation of settings as the position of the hood sash changes.

With simplicity in mind, the control system at Bucknell makes appropriate use of the sophisticated VAV system, as well as the more basic constant volume (CV) system. While each individual lab unit works on a simple two-position lo/hi unoccupied/occupied air balance, the central supply and exhaust systems each work independently in a full VAV arrangement.

◆ **unoccupied diversified control mode.** Given the mix of academic and research labs in the Bucknell Science Center, and the need for the system to respond to diverse and unpredictable demands, the central supply and exhaust systems had to be designed flexibly to serve any combination of occupied and unoccupied rooms. The biggest potential for energy savings in a lab environment is through an unoccupied diversified control mode. Using this strategy, hood air flow and space temperature are set back on nights and weekends.

Contrary to most building control sequences where the occupied mode governs, the basic operational mode at Bucknell is designed to be unoccupied-diversified. The labs are indexed to an in-use condition according to class schedule, or the work schedule of the researcher. Occupied-unoccupied room switches are provided to permit local override if the lab is to be used when centrally-indexed to be off. The simple unoccupied mode achieves 90 percent of possible energy savings without elaborate sash tracking controls and maintenance upkeep.

◆ **air balance schemes.** The air balance scheme has also been kept simple, with supply and exhaust air kept in balance through pressure-independent air valves. A fixed air differential, made up from the corridor, keeps the lab in a relative negative condition without expensive offset controls. Here labs are maintained negative in relation to the corridor by pressurizing the corridor.

◆ **back-up strategies.** At the heart of the system, the building uses both manifold supply air and manifold exhaust air systems. Supply air handling units are connected to provide partial back-up, should one unit be down. If the unoccupied diversified mode is in effect, then the failure of one unit will not affect the overall building performance. Likewise, the hoods and general lab exhaust connect to a "ganged" exhaust arrangement. However, unlike the supply units, the exhaust fans are oversized so that should one unit go down, 75 percent of the total exhaust is still available. Again, if the unoccupied diversity is realized, 100 percent of needed capacity may be achieved.

These systems just touch the surface of the infrastructure for the Bucknell facility. The building automation systems, chillers, cooling towers, animal facility and greenhouse systems, transformers, emergency generators, systems for power distribution, fire and life-safety have been carefully engineered toward the same goal of simplicity and cost-effectiveness. Equally, systems for sanitary, storm, and lab water treatment, potable, nonpotable and pure water, and lab gas distribution, which require the same, balanced focus, are integrated fully into the building systems.

Thus, the overall result of Bucknell's HVAC strategy for the Science Center provides simple, cost-effective, and maintainable systems that are consistent with and integrated into the goals of the project.

Bucknell University New Science Center

Lewisburg, Pennsylvania

Architect: Shepley Bulfinch
Richardson and Abbott
Boston, MA

Size: 201,900 Gross Square Feet

Construction Cost: $21,946,830

Net Square Feet:	Phase I and II
Teaching Lab	19,710
Research Labs	24,400
Lab Support	18,960
Classrooms	14,185
Offices	13,900
Other	28,075
Total	119,230

Completion Date: October 1991

The central rotunda, entry pediment, and broad flight of steps create a strong visual identity for the sciences on campus.

The Science Center develops, for the first time, an integrated Science and Engineering Quadrangle on Bucknell's campus. Phase I—the new 70,000 square foot chemistry wing with connections to the renovated 51,000 square foot Olin Hall for physics and math—was followed by Phase II, the 80,000 square foot biology wing. The university's objective of integrating the sciences will be met when space for the Psychology Department is built in Phase III.

Research by both students and faculty is an essential feature of the Bucknell science program.

The Science Center is organized as a series of articulated wings and pavilions responding in scale, materials, and detailing to the buildings, and creating a campus "gateway" to the science complex and to the adjacent Marts and Vaughan Engineering Quadrangle from the Student Union and residences to the west.

Bringing Departments Together

The complex was planned to promote interaction among disciplines and to take advantage of shared instruments and facilities. At the same time, departmental desires to retain their individual identities and to have their members close to one another had to be accommodated.

To solve these conflicting objectives, the departments are organized in wings: they retain their identity vertically but are adjacent to one another horizontally on each level. To further encourage interaction, the central atrium, where chemistry and biology meet, contains faculty and student lounges, seminar rooms and informal gathering spaces. A 200-seat teaching auditorium incorporates the full range of audiovisual devices.

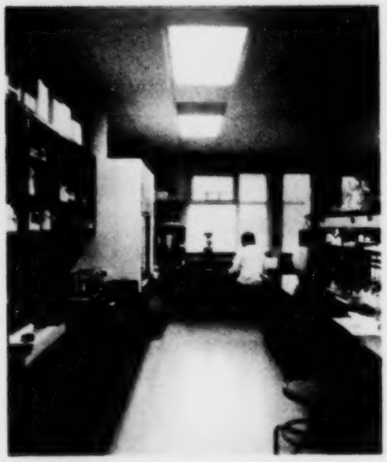
Flexibility

The plan is designed to be flexible, accommodating two differing departmental attitudes toward efficient working space and office/laboratory relationships.

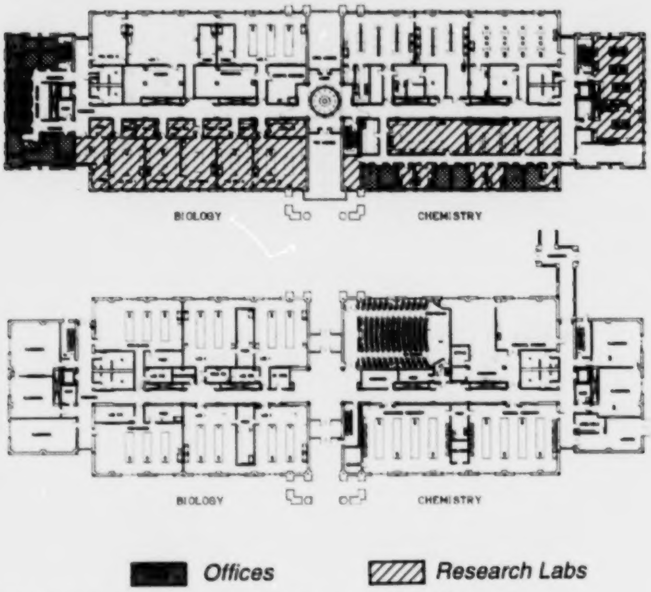
The chemists decided to locate their offices adjacent to their research labs for reasons of supervision and convenience, while the biologists located their offices together in the north pavilion to maximize the interaction between faculty members.

The two departments also arranged their research space differently. The early planning allotted 750 square feet of research space to each faculty member. The chemists planned small individual research labs of 135 net square feet, plus larger unassigned research labs which can be used flexibly as funding and needs change, while the biologists decided to create 600 net square feet of individual research labs plus small associated support spaces which will be shared.

The same planning module and large floor plate serve both arrangements and will permit reconfiguration in the future.



Biology faculty research labs were designed as generic labs with a series of optional variations.



First and third floor plans showing two office/lab patterns.

Functional Zoning

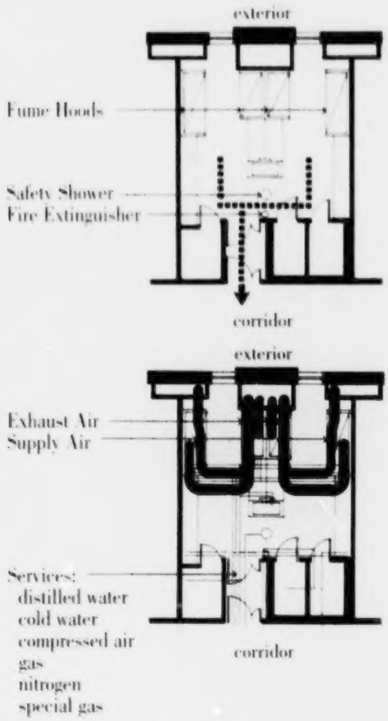
In the new building, Biology and Chemistry Departments are zoned vertically according to increasing specialization.

The first floor contains introductory teaching labs, classrooms and an auditorium, all of which require access by large numbers of students. The second and third floors contain advanced teaching labs, research labs and faculty offices. A 4,400 square foot rooftop greenhouse is designed for exhibition of exotic plants as well as research; animal quarters and storage space are at basement level.

This pattern keeps research out of the mainstream of traffic generated by lower level courses; it also relates the introductory and advanced functions for biology and chemistry to one another.

This faculty lounge and other shared spaces bring together the Departments of Chemistry and Biology at the atrium.

Cell Culture Lab



This space provides a restricted clean environment for growing cell cultures. The lab is pressurized to maintain aseptic integrity.

—Facilities Handbook, NSF.

Air Distribution Systems. The air distribution and exhaust systems you select will depend on the density of fume hoods and equipment to be used in the individual spaces, the balance of teaching and research to be housed in the building, and the extent of wet laboratories to be used. Again, think about what works and what does not work in your current air distribution system as you plan those for your new spaces.

It is common practice in laboratory design today to provide 24-hour operation with full outside air; this requires a relatively high amount of energy, but eliminates the possibility of recirculated air that can cause contamination and a safety/health hazard if chemicals are entrained to the laboratory or other spaces.

Historically, constant air volume ventilation systems which required minimum air change rates were used in science buildings. The constant volume air system offers a basic air-conditioning and ventilation system; it is a proven and tested system which will be appropriate where equipment loads and/or fume hood density dictate an air exchange rate of between six to eight air changes per hour (ach). The issues of pressurization and safety can be achieved initially when the system is balanced during construction. The system does have disadvantages, including limited flexibility for change over time (often full system rebalances are necessary). Certainly, if used at high air change rates, the constant volume air system will be energy inefficient in cooling and heating loads and fan power requirements.

With modern technology both night set-back and variable air volume systems have been developed, each of which addresses limitations of the constant volume system. Night set-back systems are effective from the perspective both of budget and environmental concerns in regard to the use of energy. In this system, outside of your normal working hours, the air-conditioning and ventilation system distribution capacity is reduced to around four ach. This reduces energy expenditure, but still ensures that any critical experiments will continue to operate safely. (An override switch is necessary to allow work outside of normal hours.)

The most recent development in air distribution systems, the variable air volume (VAV) system, not only minimizes energy use, but provides additional safety at fume hoods and maintains pressurization. This system is highly flexible, and allows for easy remodeling in the future, as minimal rebalance (pressure independent devices) will be required. The VAV system offers capital cost savings, however, these systems do increase project budgets, and thus you should perform a "life-cycle" cost exercise before selecting this option.

Noise control should also be considered as you select HVAC systems, as diffusers, variable air volume control devices, high duct velocities, and fume hoods are all sources of noise that detract from the comfort level in the building. The modern research facility often tolerates noise levels of NC50 to 55. In teaching facilities where communication is essential, noise levels of NC40 to 45 should be achieved *(NC=noise criteria curves: a means to define ambient noise level).*

The selection of duct materials is particularly important as you plan the air distribution system, especially for exhaust systems. There are many materials, ranging from stainless steel to fiber reinforced plastic, that can be used, with the choice determined by type and quantity of chemicals to be used, acceptability to local authorities, as well as considerations of cost. The detailed list of chemicals to be used in each space that was identified as you defined the program is critical information for the lab planners here.

Safety. As stated earlier, safety for students and faculty is the priority concern in the development of your HVAC systems. The primary goal of an effective exhaust system is to contain the contaminants at their source. Besides considering the location of fume hoods, ensuring adequate access around benches, and selecting appropriate architectural materials, critical issues in regard to safety include:

◆ **air flow.** The fume hood is used to carry out hazardous experiments. Air flow around the fume hood with the sash open can cause turbulence at the sash opening, which will cause chemical fumes to be drawn into the room. To avoid this, the fume hood sash face velocity should be maintained at between 80 and 125 feet per minute (fpm). A VAV system (described above) will help address this safety concern.

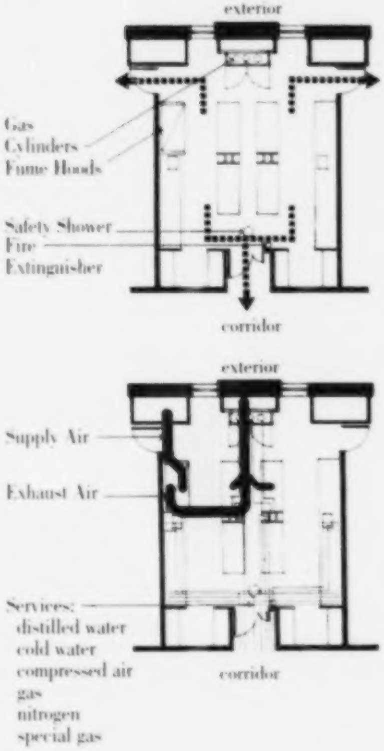
◆ **location.** Excessive air velocity at the location of the experiment can be hazardous, and thus careful selection and location of the diffuser is critical. Often in high air change spaces, laminar flow devices are used.

◆ **air change rates.** Maintaining the recommended minimum air change rate during the day is another critical consideration. During occupied hours (depending on the amount of equipment and/or the number of fume hoods), the air change rates should be a minimum of six to ten ach and often as high as twenty. During unoccupied hours, experiments can continue and need to be accounted for in setting air change rates (such experiments should be conducted only in fume hoods); it is recommended that a minimum of four air changes per hour be maintained at all times.

◆ **laboratory pressurization.** Pressurization is required to be maintained at all times. This will influence the type of HVAC system you select. The critical issue is that of the supply and exhaust air tracking that is required, whether you end up with a constant volume or a VAV system. In most laboratories, the requirement is negative pressurization to avoid contamination or movement of airborne chemicals from the laboratory to "clean" areas such as corridors and offices. In some labs, such as tissue culture or biohazard level 2 and 3 (BL2 and BL3) labs, this negative pressurization, which meets NIH guidelines, is critical to avoid positive contamination from the outside to sensitive experiments.

◆ **emergencies.** Finally, you must ensure the operation of your HVAC system under emergency conditions. If there should happen to be a power failure or a fire, it is essential that the chemical exhaust system remains operational so that hazardous exhaust fumes are removed. This

Analytical/Physical Chemistry Lab



The laboratory is arranged in a wet and dry zone for four researchers who will perform analytical and physical chemical research. The dry zone consists of a desk area (study carrels) and the wet area includes experiment work surfaces and fume hoods.

—Facilities Handbook, NSF

can be achieved by providing an emergency power system to all critical exhaust fans and controls.

This discussion on safety merely highlights some of the most important issues internal to your spaces that must be considered as you plan the HVAC system for your new facility. Be aware also of the local, state, and national codes and regulations in this regard as your planning proceeds.

◆

In some circumstances, gaining the support of the neighboring community for your project will depend upon the real or perceived impact on the environment. Education and communication are key to addressing such concerns, both on- and off-campus.

◆

There are also issues that affect safety external to the structure. The discharges from science building exhausts require careful analysis during the design stages. The effects from these discharges can be hazardous to the surrounding environment. The American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) has basic recommendations on good practices for the relationship of exhaust discharge to outside air intake, and your lab designers or project manager will be familiar with them. Most often, however, specific studies are required to determine what will work best in your specific situation. These can be carried out by wind tunnel studies and computer analysis.

Good practices to reduce the effect that fume discharges have on the environment include dilution of chemicals, possible filtration, and discharge velocity (greater than 3,500 fpm). Manifolded exhaust systems, with plenums located on the building roof, allow for dilution of chemicals with general building air exhaust. This approach allows for maximum dilution within the building confines before exhausting to the atmosphere.

The use of computers to simulate experiments, new approaches to teaching and research that focus on a research-rich environment for students and faculty alike, and greater concern about safe laboratory practices all are having an impact on laboratory cost and design. Although it is unlikely that the wet laboratories of today will disappear altogether, as you plan, be certain to develop HVAC systems that are flexible and adaptable to accommodate changes to your programs of teaching and research over the life of building.

Finally, there are issues beyond ventilation systems that must be addressed to ensure a safe environment for building users. The handling of dangerous material in your labs, equipment for proper storage, proper handling procedures and personal protecting garments must be priority concerns. Proper equipment for chemical containment must be worked into the design of the facility from the start.

Safety planning for a laboratory must not be limited to protective garments for users, or the establishment of safe handling procedures. In your planning, you must incorporate design characteristics that safeguard health by providing a proper working environment and equipment, including emergency showers and eyewash units. Informed discussion is the key to good laboratory design. As with all stages of the planning process, the collaboration of building users and persons on campus with experience with and responsibility for maintenance of the HVAC systems, working closely with consultants in lab design, health and safety, is essential.

THE IMPORTANCE OF CHEMICAL CONTAINMENT

The Laboratory Designer's Perspective

Applying the *source/path/receiver* concept to safe laboratory design provides a basis for control of potential chemical contamination. This concept means that control is implemented first (to the extent possible) at the *source*—where the chemical contamination may originate. Containment at the source is primarily accomplished in laboratories by the use of engineering controls, such as ventilation and hoods. While engineering controls could be designed to provide absolute containment of almost any type of chemical hazard, the cost of such systems would be prohibitive in all but the most crucial circumstances.

Thus, it is usually impractical and unnecessary to rely solely on engineering controls in most chemical laboratories. As a result, consideration of contamination control shifts to the *path*. By path we mean the route chemical contamination takes going from source to potential *receiver* i.e., the worker. Control along the path relies on using proper techniques and procedures.

In the event total control at the source and along the path is not feasible, final reliance for safe laboratory design is on the use of effective personal protection. It should be cautioned that sole reliance on personal protective equipment and clothing should be avoided; it provides no redundancy; relies heavily on the worker's discretion for proper use; requires periodic upkeep and maintenance to ensure effectiveness. It also may provide a false sense of security.

The *source/path/receiver* concept should always be a fundamental consideration in the design of any laboratory in which chemicals are used. In this system, operational practices protect the receiver/worker from potential contamination along the path while the work is performed. If a mishap occurs during work operations, control at the source (engineering and storage) provides backup protection or redundancy, but is not relied on as the exclusive means of protection.

A successful chemical hygiene program relies first on knowledge. Knowledge is needed on the specific chemical or class of chemicals planned for use in order to understand the unique physical, chemical, and toxicological properties of the substances. It is also necessary to understand the type of work planned and the amounts of chemicals routinely used. While there is overlap in some aspects between laboratories used in teaching, research, consulting, analytical chemistry, synthesis, etc., each laboratory has its own unique characteristics and requirements. This combined knowledge helps determine the proper controls required to control the potential hazards which may exist. This information is also used in: laboratory design; handling, storage, shipping and transportation of chemicals; training; medical surveillance; monitoring; spill control; emergency response; decontamination; and waste disposal.

There are three other critical factors in establishing a safe laboratory environment:

- ◆ Engineering controls are essential in order to contain contamination at the source
- ◆ Proper chemical storage is needed again for control at the source
- ◆ Effectiveness of all safeguards depends on the establishment of proper work practices based on the industrial hygiene principles of anticipation, recognition, evaluation, and control.

Protection of the worker and the environment is always paramount in any facility where chemicals are used. Combining the *source/path/receiver* concept with a chemical hygiene program helps achieve this objective. The goal of chemical health and safety is to maximize containment and minimize contamination.

CHEMICAL HEALTH AND SAFETY

The University of Missouri Story

The University of Missouri is a large midwestern publicly-funded system with four main campuses which serve students in all regions and major cities of the state. The Science and Technology Focus Group of Hellmuth, Obata & Kassabaum is involved in programming, planning, or design of five projects for the university on three of its major campuses. The age and condition of the existing facilities in these five projects that the University of Missouri are confronting are formidable. Buildings range in age from the early 1920's to 1970's. Only one of the building's studies is under 15 years old.

Each project, although unique in its particulars, has four major goals in common:

- to bring related scientific and educational activities closer together and increase interaction
- to improve the facilities' environment so that students who are attracted to the sciences and faculty can be recruited and retained
- to improve safety of the laboratory facilities
- to meet current codes and building standards.

These diverse science facility projects addressed common issues of chemical health and safety. Although the University of Missouri has an excellent hazardous waste disposal program, chemical stockroom facilities are generally unimproved and are poorly ventilated. More importantly, entire lab buildings lack sufficient supply air. Inadequate ventilation and improper differential air pressures are major causes of chemical and other odors in hallways and of heavy corrosion of metal laboratory fitting and fixtures. Although these conditions are not limited to laboratory buildings over 20 years old, they are so common in older facilities that they are called the *"old lab syndrome."*

Besides being unsightly and unpleasant, do these conditions cause any harm to building occupants or to students? Yes, they can. Harm may come in the form of chronic respiratory infections or allergies caused by exposure to mold, spores, and microbes outdoors that are literally sucked into lab buildings by air pressures in the building less than outside. Harm may be done simply in that there is no capacity to add fume hoods where they are needed for researchers. Harm is low ventilation in labs insufficient to dilute chemical fumes and vapors. Chronic respiratory exposure to some chemicals can lead to sensitization in certain individuals.

What can a university system do to improve lab conditions? First, the university set goals. Second, it developed a program document that determined the departments' needs and discovered the problems particular to each project. Third, the university investigated the feasibility and the extent of renovations required to meet their goals and space program. Fourth, they made decisions on the planning strategy:

- simple cosmetic upgrade
- full renovation including infrastructure
- new construction for building addition
- replacement building.

These decisions were heavily based on the state funding process and financial resources available to the campus and departments.

UM–Columbia Campus. At UM–Columbia, the faculty in the School of Natural Resources is located in over four buildings scattered across the largest of UM's four campuses. Renovation had to be dismissed as a realistic strategy, because no current building had sufficient empty area to accommodate the full program. Three of the existing buildings are well over 50 years old and no longer support the kind of extensive research activities common today. The university chose to erect a new replacement building on this campus.

UM–Columbia chose a different strategy for the Department of Chemistry. There are three buildings currently occupied by chemistry, from 70 to 35 years of age. Schlundt Hall, the oldest of the three, houses many of the undergraduate teaching labs. The cost and difficulties to bring the basic building up to code, to improve the lab conditions and chemical handling are considerable. The main Chemistry Building, however, has a well-proportioned modular plan and meets most code requirements, but it lacks adequate supply air and fume hood capacity, and so suffers from the *"old lab syndrome."* After careful study, UM decided to remove the undergraduate teaching laboratories from Schlundt Hall and the Chemistry Building and locate them in a new addition to be attached to the Chemistry Building. This allows new state-of-the-art teaching facilities that provide enough fume hoods to train and protect all the undergraduate students of chemistry and greatly improve chemical handling and distribution. Schlundt Hall then will be put to its highest and best use as the library, classroom, and administrative center for the Department of Chemistry with reasonable cost for renovation and code compliance.

Similar to the decision UM made for the School of Natural Resources on this campus, UM reasoned that construction of a new building is the solution. The buildings currently occupied by each of these schools of associated medical sciences are too old, small, and costly to renovate for new, up-to-date scientific research teaching activities. The School of Pharmacy has to move some of its operations five miles to reunite its faculty and join its new partners for this building. The vacated pharmacy building will be put to good use for less intensive undergraduate biology activites.

UM–St. Louis Campus. On the St. Louis campus nestled in the beautiful hills of a former golf club site, most buildings date from the 1960's. The existing three buildings in the Science Complex show major damage from the *"old lab syndrome"* even to the extent that mortar between bricks has eroded causing major water damage inside. The planning study concentrated on renovation strategies for each building. Stadler Hall has the least favorable conditions for effective laboratory upgrade because of low floor-to-floor height. UM decided to eliminate laboratory occupancy on the lower floors of Stadler and use them instead for classroom, dry lab, and office uses which do not require great volumes of supply air. Laboratories will remain on the top floor where requirements for major mechanical upgrade can be met effectively and at reasonable cost.

Benton Hall's three lobe configuration is conducive to phase renovation. Vertical chases for new ventilation distribution can be constructed through the existing structure. Area for new air handling equipment was found on each floor. These factors and Benton's capacity to accommodate activites for both the chemistry and physics departments convinced UM to renovate Benton for laboratory occupancy.

The Research Building, a 1980's research lab, had its air supply drained by the two older labs connected to it. By planning air locks in connecting corridors and by increasing air supplies to the two old buildings, the newer building will be rejuvenated readily and be cured of its *"old lab syndrome."*

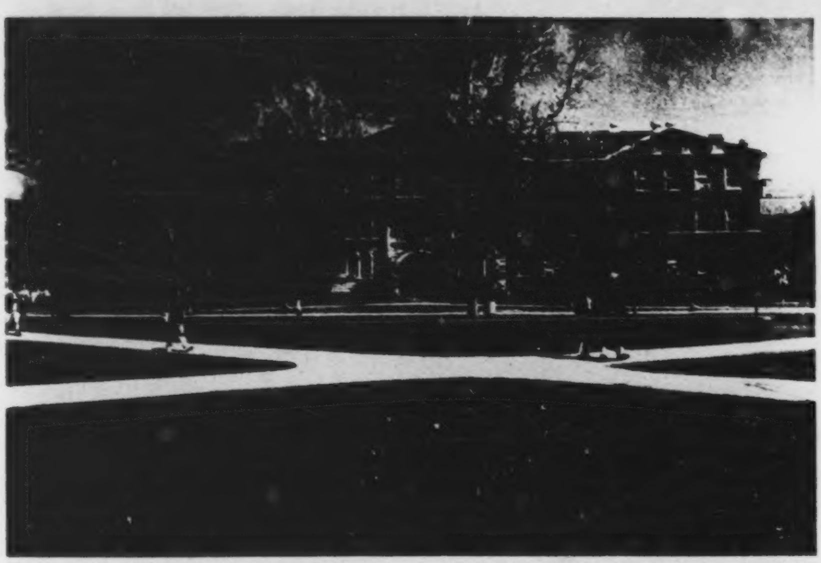
UM–Kansas City. The challenge for UM's Kansas City campus involved bringing together onto the same campus three academic programs which have a lot of overlap in teaching, research, and community service. The Schools of Pharmacy, Nursing and the Institute for Human Development will share a new mixed-use building in the heart of Kansas City's academic medical center.

Conclusion. Universities face very hard decisions to make when they encounter science departments and facilities with signs of *"old lab syndrome"* on their campuses. Decisions to renovate or to build new are complex and require time to evaluate thoroughly the existing building and to generate a good space program for the faculty involved. By completing both of these steps, the feasibility for truly improving health and safety conditions for science education increases significantly. Today universities don't have funds and time to throw at buildings with *"old lab syndrome."* One lesson from these case studies is that sometimes it is far better for science faculty to walk away from their old beloved labs. University administrators can use funds wisely by finding other occupants to make realistically the highest and best use of their old buildings on campus.

University of Illinois Noyes Laboratory Building

Urbana, Illinois

Architect:	RUST Environment + Infrastructure
Size:	Existing 180,000 Gross Square Feet
Phase I:	Renovate 30,000 Gross Square Feet
Construction Cost:	$6,000,000
Net Square Feet:	
Laboratories	15,000
Classrooms	1,000
Lab Support	3,000
Other	5,000
Total	24,000
Completion:	December 1995



The existing Noyes Laboratory Building provides instructional and research facilities for the School of Chemical Sciences.

Located on the main quadrangle in the center of campus, the Noyes Laboratory Building houses research and teaching laboratories for the undergraduate level chemistry curriculum.

Achieving a 21st century interior in a 20th century building.

The building's prominent location influenced the university's decision to renovate it rather than relocate the teaching laboratories to a new building on a different site.

Adaptation

Since the original Noyes Laboratory Building was completed in 1902, the discipline of chemistry, its curriculum and instructional strategies have changed dramatically.

When additional courses were incorporated, new teaching labs were added wherever space became available. As a result, student laboratories for each department became separated from each other. This made it difficult to support them with proper staff supervision and delivery of supplies.

The introduction of computers and sensitive instruments into the laboratories has required a more sophisticated environment. The increase in federal health and safety regulations has also changed dramatically, becoming more demanding. Each of these items needed to be addressed for the building to be adaptable for the future.

Master Plan

A new Chemistry-Life Science Building was built to house many of the research programs that were currently in the Noyes Laboratory. This provided an opportunity to reassess the building and determine the best use of the vacated space.

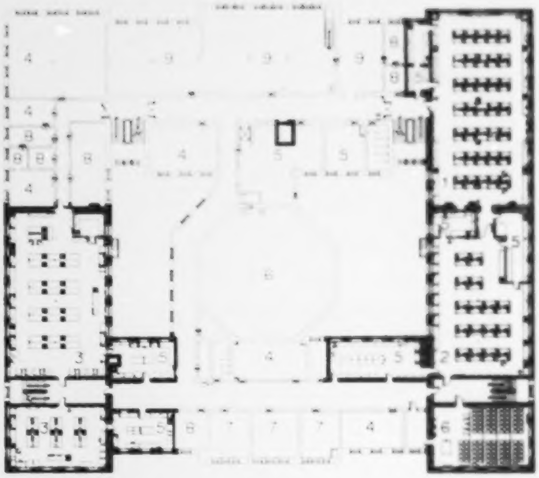
The master plan addressed the realignment of laboratories and support areas for each department. It also provided solutions for issues that had plagued the building, such as exiting, ventilation, and accommodations for the physically challenged.

Renovation

In the first phase of the project, 30,000 of the 180,000 square foot chemistry building was remodeled. Renovation included six teaching laboratories, a lecture hall, and support areas for the organic, inorganic, and biochemistry departments.

During the program verification phase, the architect met with the faculty and staff to review the physical and philosophical design requirements. Close coordination with the faculty and staff was necessary to provide uninterrupted services to students during the academic year. The nature of teaching chemistry requires students to move throughout the laboratory carrying chemicals and glassware. Adequate aisle space was important for safety reasons.

To further ensure the safety of the students and instructors, good line of sight was essential. Ventilation and the distribution of services had to be addressed with this in mind. Service columns and other vertical obstructions were kept to a minimum. To achieve this in the biochemistry laboratories, mechanical and electrical services were delivered from below the floor.



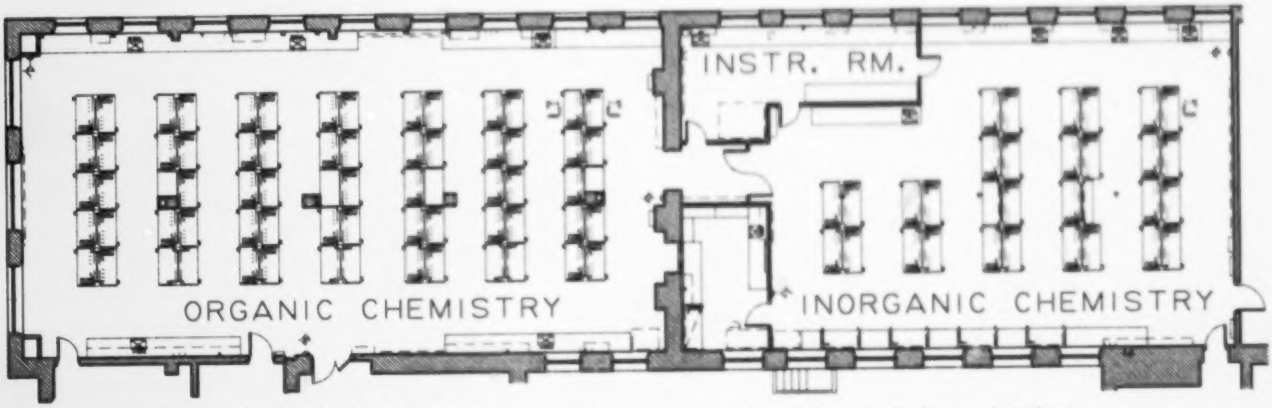
Second Floor Plan

1. Organic chemistry laboratory
2. Inorganic chemistry laboratory
3. Biochemistry laboratory
4. Chemistry reserach laboratory
5. Prep and storage
6. Lecure hall
7. Classrooms
8. Office
9. Chemistry library

Design priorities for chemistry teaching laboratories:
- **Appropriate ventilation**
- **Good visual sight lines**
- **Adequate aisle space for safe student circulation**

Containment of chemical fumes is critical in the organic and inorganic laboratories. Individual student ventilated workstations were designed with the same features as a chemical fumehood. This restricted the line of sight. To reduce the problem, clear safety glass on the sides and rear of each unit allows the instructor to see the maximum number of students at one time.

The glass-enclosed, individually ventilated student station allows for good line of sight.



Organic and upper-level inorganic chemistry sections are able to use the same student ventilation workstations.

Note the exceptional use of natural lighting with floor-to-ceiling glass and clerestory windows. This natural light is supplemented by cable-hung fixtures located over the edge of the laboratory benches that produce both direct and indirect light. There are also locally controlled task lights located below the bottom reagent shelf.

Note how the placement of the recessed fluorescent light fixtures is coordinated with the edge of the laboratory benches to help prevent shadows.

Lighting Systems.

Lighting requires particular attention, both from the perspective of energy consumption and from the perspective of the effectiveness of the spaces for work and for the life of the community. Daylighting should be incorporated as much as possible, as it provides free energy and links the interior environment to the outside in a way that contributes to the *spirit* of the building. The aim of good lighting (artificial and natural) is to enhance work spaces and to provide a suitable environment for all building users, students, faculty, and staff. It is important to remember also the impact of color for the lighting design. Pale colors surrounding the work space ensure that students and faculty will be able to focus on their work. When color rendition is critical for the task, light sources that match daylight as close as possible should be used.

Lighting will consume about one-third of the energy used in the building, and therefore requires particular attention as you plan for an energy efficient building. By combining energy efficient lamps and fixtures, automatic lighting controls and dimming systems—and daylight—into a lighting system for your building, you will be able to make most effective use of both the natural light and the required artificial lighting. Obviously, daylight needs to be controlled to avoid glare and excessive heat gains.

Consider lighting parameters:

◆ **reflectance.** For surfaces and fixtures in a typical teaching space, recommendations (from the Illuminating Engineering Society of North American (IES)) are: ceilings—70-80 percent; walls—40-60 percent; floor and desktops—35-50 percent.

- **direct glare.** Glare distracts and causes discomfort to building users. To prevent glare from direct sunlight, use sunshade devices such as solar blinds, baffle systems, and overhangs. For lighting fixtures, glare can be avoided by the use of low brightness louvers or diffusers; indirect lighting should also be considered, especially in areas where computer terminals are to be used.
- **lighting levels.** Lighting levels are determined by the task to be performed. IES recommendations are 50-75-100 foot candles (fc) for illumination on task in lecture rooms (audience), reading rooms and laboratories. For lecture rooms in which demonstrations are to occur, the recommendation is 100-150-200 fc for illumination on task; for general faculty offices and conference rooms, lighting levels at 20-30-50 fc are adequate. For general circulation areas and toilets, 10-15-20 fc should be provided for general illumination throughout the spaces.
- **light fixtures.** Energy efficient lamps, such as T8 and compact fluorescent lamps and high intensity discharge lamps, should be selected insofar as possible. Lamps with electronic ballasts provide good illuminance output, as well as long life, and low energy consumption—all important considerations. In addition to energy considerations, light fixtures should be selected for greatest efficiency of light output, as well as for reduced glare. Plan the layout of light fixtures at the same time as the interior furniture is being designed and located, so that optimum lighting levels are achieved for each specific task/area. Task lighting should be considered to supplement ambient lighting levels.
- **lighting control devices.** The simplest way to control lighting is to provide separate switching of each group of light fixtures; automatic lighting devices such as occupancy sensors, and/or central control lighting systems using programmed logic control panels can be used. Although such automatic devices require a higher initial capital cost, the life cycle cost often balances out. Many local power utility companies provide incentives to customers using such systems, and these must also be considered and explored in the selection of lighting controls.
- **security.** A good security lighting system around the perimeter of the building and after-hours lighting in the interior are needed to provide a safe and secure environment for building users, and for security officers. Lights in and on walkways, parking lots, and interior corridors should remain on at night.

In selecting lighting systems that will serve the purposes of your building, and in determining their layout and location, you have many things to consider, including maintenance and cost, and initial cost versus life cycle cost. For aesthetic reasons and for ease of maintenance, it is also important to have lighting systems accord to a campus standard.

As with all other technical issues that you are considering, the most successful lightening systems will require informed discussions between building users and persons from on- and off-campus with the appropriate expertise. It is the responsibility of the project manager to see that these discussions take place and are productive.

Building Controls. Building control systems should be considered based on cost, appropriateness for your specific project, and the level of on-campus expertise to operate them. Control equipment, whether pneumatic, electronic, or direct digital controls, should be located adjacent to the equipment it serves and thus take up minimal space. A control room to house the computer terminal should be provided within the building if a direct digital control system is to be utilized.

Contemporary science buildings use direct digital controls on a majority of the systems within the building, however pneumatic controls are used to control laboratory pressurization because of their fast response time. Hybrid systems, such as direct digital controls/pneumatics, require careful coordination during design.

Laboratory spaces have quite varied electrical needs. It will be important to know the electrical needs for each space, allowing for existing instruments, apparatus, and computers, as well as that anticipated for the future. One way of allowing flexibility without paying for the cost of capacity not yet needed is to install a series of raceways along lab benches and walls. Necessary electrical outlets can be installed at the time of construction, and additional outlets and wiring then added as needed. This approach requires that electrical distribution panels and service be oversized at the time of installation to allow for easy expansion. (These raceways can be dual raceways allowing communication wiring to be run in the second channel to provide flexibility for the computer network system as well.)

Some types of equipment require specialized voltages of types of power, and those needs should be identified or anticipated as best as possible through interviews with users. Outlets in the walls and/or floor of flexible classrooms can allow the use of computers at a future date. If you have spaces in corridors where you anticipate students will gather and study, you may want to provide electrical outlets for their laptop computers.

Energy Conservation.

Science buildings tend to be high users of energy, yet often capital budgets do not allow appropriate and necessary energy saving devices. You should consider energy consumption and conservation at every stage in your planning. If you are building anew or undertaking major renovations, set energy goals based on codes and standards for the new spaces; in establishing budgets for the building, develop one for energy use that takes into account building design, equipment cost, and energy use over the life of the building. Information about the local climate can be used in computer analysis to determine how different design approaches might utilize energy more efficiently in the construction and in the use of the structure.

Susquehanna University

Selinsgrove, Pennsylvania

Architect: Celli-Flynn and Associates
Architects and Planners
Pittsburgh, Pennsylvania

Size: 68,000 GSF

Construction Cost: $5,548,165

Net Square Feet:

Geology (ground floor)	3210
Physics (first floor)	3270
Biology (first/second floor)	7280
Chemistry (third floor)	7070
Total	68,000

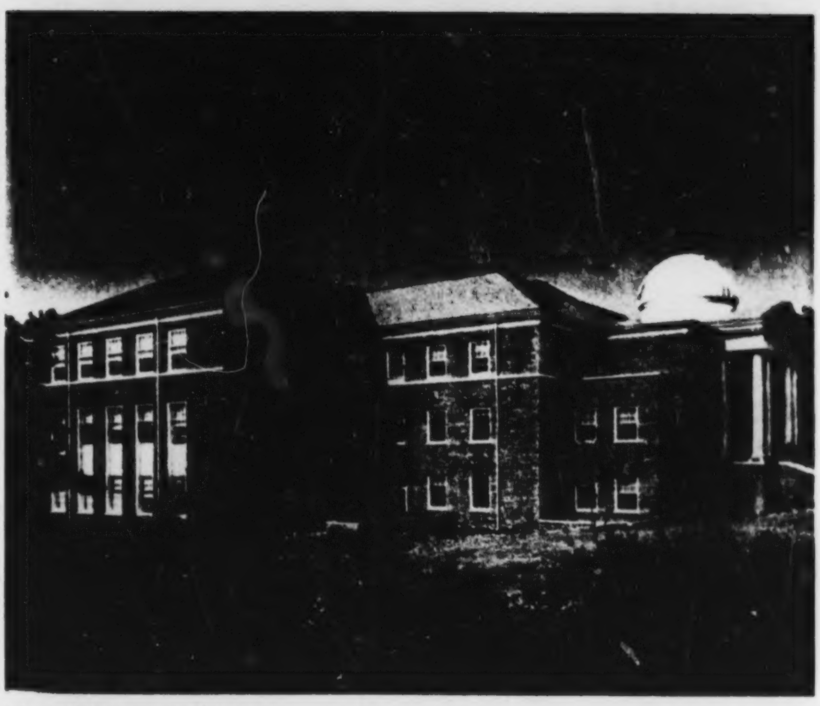
Completion Date: 1990

This 68,000 GSF building houses teaching laboratories for biology, biochemistry, chemistry, geology, physics, psychology and faculty research laboratories. The building addressed a number of campus planning issues in its design. North/south circulation paths and east/west approaches were reordered. A focal point (the atrium) occurs where these two paths cross. Science has been put "on display" at the heart of campus movement.

Faculty, students, and visitors consistently praise the attractive and genial environment.

History

Fisher Science Hall was originally built in 1962 to house the three departments of biology, chemistry and physics and to serve a student population of 1,150. The large open labs and the lack of smaller dedicated laboratories made Fisher increasingly inadequate for contemporary instruction and research.



View of the new addition.

Planning

The science faculty at Susquehanna in the 1980's, with few exceptions, was the same science faculty in place when Fisher was built in the 1960's. Science enrollments, once robust, had been in slow decline for more than a decade; conversations had begun about eliminating the department of geology. Led by the Dean of Arts and Sciences, the science faculty engaged in an intensive strategic planning exercise between 1987 and 1989 which included external evaluation of each department, extensive curriculum revision, and research leaves for two-thirds of the science faculty as they prepared to implement the changes planned. The university committed to a renovated and expanded science facility as the first priority of an ambitious capital campaign, and Celli-Flynn was selected in a design competition to be the architects for the new building.

From months of interaction with senior staff and conversations with science faculty, the concept emerged of a "science neighborhood"—a building that would not only support contemporary science instruction but also foster the interdisciplinary collaborations important to today's scientific research.

The 1990 renovation and expansion of Fisher Hall took what was a factory-like rectangle with departments isolated in their various territories and turned it into a welcoming, synergistic environment organized around a three-story central atrium. The original 45,000 square foot building was expanded with a 23,000 square foot addition on its north side. An observatory, containing one of the largest telescopes in Pennsylvania, was added, creating an integral architectural element in the classical facade of the new addition. Where the old building was architecturally nondescript, the new Fisher Hall is a proud Georgian building at the center of the campus.

Additional square footage for geology classrooms, laboratories, and offices was gained by further excavating and renovating the ground floor of the old building and using the topography to advantage to add more ground floor space in the new construction. Psychology and physics share the first floor; biology is on the second and chemistry on the third. Traffic among the depart-

By minimizing the need for air-conditioning whenever possible you will take a major step toward energy conservation. An optimal building fabric design, one with high insulated walls and low energy windows, will reduce environmental effects on the interior of the building. As discussed earlier, your decisions about building orientation (for example, being able to use passive solar to its maximum benefit), will have implications for energy conservation or consumption.

Many decisions made throughout the process will affect the energy gains and losses in your new building. Night set-back controls or variable air volume controls, if selected, will lead to a reduction in energy costs over systems that operate 24 hours a day on full outside air. Further, the use of energy-efficient equipment, such as motors, chillers, variable speed drives, is also recommended as a means to reduce both use and cost of energy. In some climates, energy-reclaim systems (between exhaust and supply air systems such as run-around coils) offer good payback over the long-term.

A key to energy conservation is the selection of the control system. The direct digital control system, which uses software and electronic controls, offers many energy saving opportunities, but an educated operator is essential to secure maximum benefits from such systems. The greatest energy conservation measure is education, and a "buy-in" by users is essential from the earliest stage of your planning. Building users should be alert to energy conservation measures that they have control over, including switching lights off and closing fume hoods, and allowing for reasonable swings in temperature.

Computers and Networking.

One way in which contemporary facilities differ from those of the past is that they must accommodate sophisticated technologies for computing, those already available and those yet to come. The technology that is now available provides the means to access knowledge in ways that are having an immense impact on how teaching, learning, and research is done. Computers linked both internally and externally serve as communication bridges between student and student, student and faculty member, researcher and researcher. Thus a carefully designed, sophisticated communications network system that is fully integrated into the fabric of the building is vital to ensure the successful operation of a facility for science and mathematics that will work today and for the foreseeable future.

To accommodate these new technologies and the new approaches to teaching and research, a new building utility has been created to take its place with the building systems for air-conditioning, power distribution, and the communications network. This network consists of high-performance cabling, sophisticated electronic equipment, and integrated software applications that act in concert to deliver these systems to the users of the building.

In planning to accommodate the range of information technologies now available for use by students

Virtual reality (VR) is a technologically generated illusion by total immersion in a 3-dimensional environment, which can be navigated and manipulated. VR promises to revolutionize education, science research techniques and medical procedures, as well as industrial processes, once the potential has been turned into a technically and economically viable industry. This maturing is expected to take five to ten years, well within the life of a science building (built today).

Virtual Physics. For physics students....a virtual laboratory has been developed where experiments in motion and gravity may be undertaken.... The lab provides a first look at how VR may be used in teaching basic physics concepts. A student can learn about gravity and Newton's Laws—not just be reading, or watching a demonstration—but viscerally, through experimentation and trial and error. Time can be stopped or slowed to observe what happens in a fast-moving experiment. The simple and intuitive interface does not impede learning, and to a large extent, the teacher's attention is not required while the student is in the lab. (There's nothing to break or blow up!)...typically in a networked system...the teacher would enter the lab when needed, then move on to another student, all without leaving his or her desk. (From "Where Virtual Rubber Meets the Road," Ben Delaney, Virtual Reality 93.)

—*Lab Design for the Future*,
Anshen + Allen.

and faculty, consider first the network infrastructure:

◆ **equipment rooms.** Computer rooms and equipment closets will be needed to house the file servers, high-speed storage devices, and other networked resources. Both should be environmentally conditioned (to control temperature and humidity levels); the computer room should be provided with a clean power supply, typically supported by a generator or an uninterruptible power supply (UPS) that would maintain power to equipment in the event of an emergency. There should be an equipment closet on each floor, for the termination of cabling and the housing of network equipment.

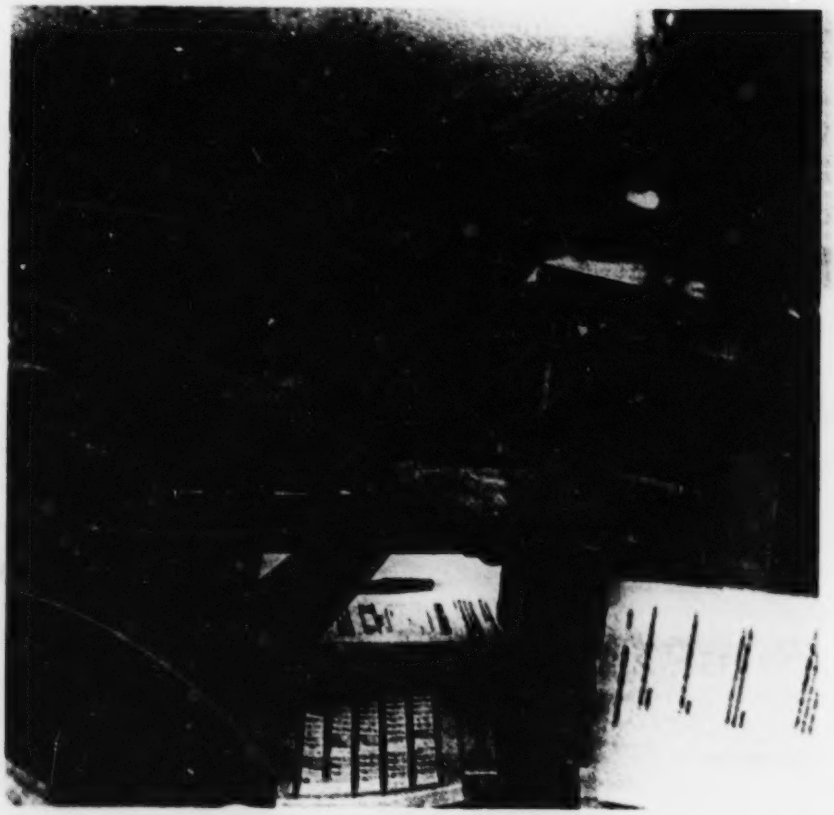
◆ **cabling system.** The second element to consider is the cabling that will run from workstation outlets to the computer rooms and equipment closets containing the network equipment. This cabling consists of either high performance twisted copper pair cabling or optical fiber cabling running in a star topology, with the computer room or equipment closet at the center and the workstations spread out around it. Copper cabling is traditionally used in the run between equipment closet and workstation, due to its relatively low cost and ease of installation. Optical fiber cabling is more likely to be found connecting the equipment closets to the computer room (this is the backbone) or connecting the workstations that require an extremely high-speed connection to the network.

At this time, due to the steadily increasing need for network speed to support sophisticated multimedia applications, planners are looking more closely at installing optical fiber to carry network signals in the horizontal cabling that runs between workstation and equipment closets. This has led to the introduction of innovative approaches to the installation of optical fiber cables, such as the air blown fiber (ABF) technique, which consists of narrow bore plastic tubes that are installed to each workstation during the construction of the building. Thin optical fiber cables are then "blown" into the tubes using compressed air, as and when required. This has the advantage of reducing the initial cost of the installation, while allowing the decision regarding what type and quantity of cabling to be made at the last responsible moment.

The Future. Developments in the field of communications technology are progressing at a rapid pace. Advances in computer technology, network systems, and software applications allow users to perform tasks, undertake research and communicate with others in ways that were only dreamed about ten years ago. There is no reason to expect that the pace of change in regard to communication technology will slacken. If you are building into your academic program opportunities for students to use technology to learn by inquiry, exploration, to be prepared to identify, organize, and solve problems once they leave your campus, being wired for the revolution in learning will help you achieve those goals for your students.

Of particular importance to your planning process, the next few years will see the development of high-speed wireless communications that, coupled with the increasing availability and reduced costs of laptop computers, will allow your students and faculty to access information databases, write and respond to electronic mail and participate in videoconferences without requiring a physical connection to a network access point. The potential for connecting to network systems without being tied to a power receptacle and network point will allow the traditional approach of dedicated computer work locations to be replaced by a more freeform *compute where you sit* approach.

The growth of videoconferencing and distance learning will have a significant impact on the way we perceive modern education. Students will be able to attend lectures, talk with their tutors and peers, and submit term papers, all without needing to visit the facility physically. This will challenge building planners to rethink requirements for classrooms, lecture halls, and other spaces, both in regard to size and character of the spaces. More spaces can be devoted to the social interaction that will still be a requirement of undergraduate life, with communal areas for meeting friends, colleagues, and tutors. By integrating technology appropriately into the modern educational facility, we can truly create a classroom without walls.



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THE SMART CLASSROOM—CONNECTING TO THE FUTURE

The Columbia University Story

The chemistry faculty at Columbia University has launched an ambitious plan for making sweeping changes in *what we teach and how we teach* undergraduates, designing the *chemistry curriculum for the 21st century*. The plan is based on the use of hypermedia technologies and multimedia information delivery systems, systems that take advantage of the transformation of how people learn by using electronic communication and by visualizing information. Our plan, called the Edison Project, calls for the construction of multimedia classrooms and laboratories (smart classrooms) that will be equipped with the full range of communications technologies available today.

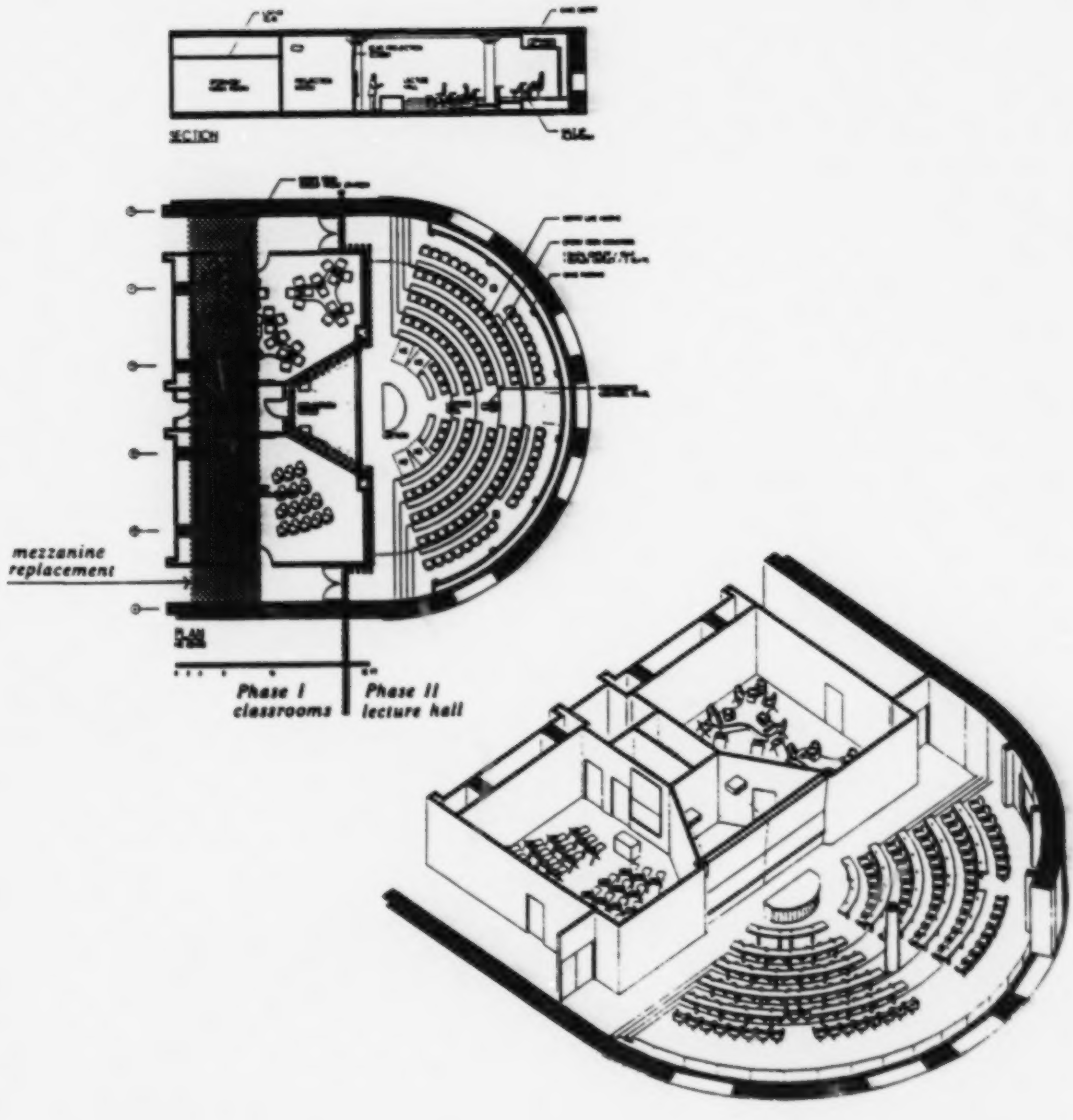
At the heart of our approach to changing the chemistry curriculum is the use of powerful computer graphics programs that are already on the verge of becoming one of the most important tools in visualizing complex structures. With these programs, it is possible to build molecular structures on the computer screen, generate three-dimensional perspectives, rotate structures, design moieties that recognize others, and simulate the dynamics of molecular motions.

A whole new dimension in understanding opens up as students become able to express themselves visually. Students can be taught to use existing programs, which are powerful tools for simulation and modeling; they can also be taught to create their own (albeit simpler) animations using object-oriented programming routines. Even students with no programming experience can be taught how to create simple animated story boards and graphics routines to help explain or clarify ideas.

Thus, our goal is that chemistry students at all levels have the benefit of visualizing chemistry on the computer screen. Toward this end we are creating a visualization laboratory for undergraduates, integrating visualization devices into our curriculum, and creating means to transport animations, images, and interactive computer graphics into classrooms, and onto the campus electronic networks. We have begun to develop interactive tutorials and simulation modules that can be used to conduct complex thought experiments and pose "what if" questions in the course of a lecture.

Our new computational laboratory and classroom contains four Silicon Graphics workstations loaded with a wide array of chemistry software packages for student use. We have equipped a 120-seat smart classroom with a flexible presentation station in the middle of a tightly curved, semicircular arrangement of seats (to insure maximum potential for interaction between student and instructor). The projection system can display information from Macintosh or PC platforms, or high end workstations (SUN/SGI), all of which are immediately available in the room for that purpose. Students can plug in laptop computers and operate them at their seats. Information from each computer is displayable to everyone in the class via the projection system in the classroom. The rear projection room also serves two smaller rooms, a computer classroom and hypermedia room, and a classroom equipped for visualization and multimedia presentations.

Once we have completed the process of developing animated modules, which will run on PC or Macintosh platforms using adhering packages like Macromedia or Authorware Professional and have completed the development of our "smart classrooms," we may be heading toward a paperless learning environment. All the information that students need will be available to be transferred and accessed on demand through electronic means. If students need to write, they will be able to do so on Newton-like thinkpads. Professors will be able to do the same, and both can view each other's scribblings privately, or on the projection screen in real time. Yes, we will still use chalk and blackboard, pencil and paper, but by helping students use electronic means to express themselves visually, we believe we will have taken a major step in transforming education on our campus.


SECTION
mezzanine replacement
PLAN
Phase I classrooms
Phase II lecture hall

In some cases, a student with a disability may require special accommodations in the laboratory.... Many modifications are inexpensive. Here are a few examples:

◆ The easiest modification to make —and one that makes for good laboratory practice for all students—is to clear the aisles and work surfaces. Students who use crutches or a wheelchair, as well as students who are blind, will move more easily in an uncluttered lab.

◆ A chemist who uses a wheelchair may have a rotary evaporator with a built-in mechanical jack for raising the apparatus. One describes his as "nothing special, simply one of several models listed in the catalog, but it is the one that best suits my needs."

◆ A geologist with no arms uses an electron microscope equipped with foot controls. The modifications were designed and built by a laboratory colleague.

◆ Some students who can comfortably transfer from a wheelchair may prefer to do lab work in a straight chair fastened to a platform on casters. The platform raises the user to a practical height for manipulating laboratory equipment in tight lab spaces.

The following suggestions can help make your laboratory safer for everyone:

◆ Have visual alarms for students who are deaf or hard-of-hearing. Flashing-light or sensory alarms (to indicate on/off status) are widely available commercially.

◆ For students of short stature or those who use wheelchairs, add extension hoses to eye and face washes and lower the pull chains on drench showers.

◆ Have emergency lighting in case of power failure.

◆ Incorporate telecommunication devices for the deaf (TDDs) wherever there are telephones.

Students who have mobility impairments can and have worked successfully in the laboratory. Necessary accommodations can vary from moving a desk around to redesigning the workstation. Helpful adaptions include:

◆ aisle width of 60 inches, to allow a wheelchair to maneuver easily

◆ controls for safety and utility equipment that are easy to reach and to use. Faucets and valves with lever handles, push-plate switches, and large push buttons can be used conveniently by people with limited strength and dexterity.

Adapted with permission from *Laboratories and Classrooms for Science and Engineering*, American Association for the Advancement of Science.

Accessibility and Usability.

Laboratories for teaching and research are highly specialized facilities, and as such present unique challenges to designers who wish to make them accessible for all users. In the context of civil rights legislation such as the Americans with Disabilities Act of 1990 (ADA) as well as state, local and other national standards (ANSI A117.1 and UFAS), design professionals have both significant regulatory obligations and a bewildering array of guidelines from which to develop detailed accessibility strategies.

Perhaps more important than any specific means to making a laboratory accessible is the recognition on the part of planners that accessibility covers not just mobility-impaired persons but those with visual and hearing impairments, learning and emotional disabilities, and those whose disabilities are only temporary, as might be the case with an injury that requires one to use crutches or an eye patch. Furthermore, the user's ability to function is affected by age, health, and external factors such as ambient noise, glare, and air quality. Therefore, it is essential to integrate *Universal Design* (as it is known) into our design attitudes and think broadly about who can benefit from this mindset.

Focusing primarily on laboratories and related support spaces, there are four basic areas of concern: casework, benches and shelving; floor-standing equipment such as fume hoods; movable or benchtop equipment; and controls and alarms.

Laboratory Casework. Most casework systems, whether the wood or metal "box" type or the more adjustable (and expensive) C-frame type, are inherently somewhat adaptable, in the sense that modifications in benchtop height and drawer stack position can be made without excessive cost or difficulty. Accessible bench positions can either be designed as part of the initial fitout of a particular lab space, or created at such time as an individual with a disability requests accommodation. Although the ADA Accessibility Guidelines (ADAAG) can be interpreted to require an institution to build-in a certain number of accessible bench stations (whose dimensions are most affected by wheelchair access parameters), it might turn out that a particular disabled individual would not find the resultant workstation suitable for their needs. Accordingly, the latter approach might prove both more suitable as a means of accommodation and most cost-effective for the institution, i.e., the changes only need to be made once. This approach can work equally well for modification to shelving positions, desk and drawer configuration, and knee space.

Floor-Standing Equipment. Perhaps the most widely used piece of laboratory equipment is the chemical fume hood. While hoods are available in a range of widths and features, there are certain basic characteristics that affect access, particularly for wheelchair users. The height of the work surface and the positions of the many controls, gas outlets and accessories are among the criteria requiring specific attention. At least one manufacturer, Fisher/Hamilton, is producing accessible hoods. In addition to clear knee space beneath the work surface, other features include: the front portion of the counter serves as a "gutter" to catch spilled liquids; the controls have been relocated for ease of reach; and the sash has been modified to improve user safety. Of course, as with any user-specific design challenge, some compromises must be made; the above example has no chemical storage cabinet below the work surface. Although such accessibility comes at a cost premium, that should decrease somewhat in future years as other manufacturers enter the marketplace.

Movable Equipment. Equipment located on the desktop or benchtop is somewhat easier to relocate into accessible positions by virtue of its relative portability. Should an individual require an item to be relocated to a lower desktop or a location with more work space around it, accommodation is simple.

What is more challenging, and which does not appear to have been addressed in any significant way, is the issue of accessibility of controls, displays, and interface devises for such equipment. For example, larger numerals, greater contrast with background color, brighter display, audible as well as visual readout, larger buttons or levers would benefit not only those with sight or hearing difficulties, but all users. This is an industrial design opportunity of large magnitude, and it remains relatively unrealized to date.

> We envision a future of technology-based, discovery-oriented learning in which disciplinary and geographic boundaries become less distinct through networked, real-time teaching and research. Electronic learning libraries, direct access electronic media, and the integration of laboratory and instrumentation facilities provide concurrent learning opportunities involving simultaneous study and experimentation inquiry and verification. New technologies facilitate new forms of learning, networking, and interaction among students and faculty, and redefine their mutual roles in education. New technologies, together with advances in the cognitive sciences, provide the resources to address different learning and teaching styles. Technological and computer literacy is nearly universal, affording more and higher quality opportunities for design, open-ended problem-solving, and other hands-on experiences in precollege and undergraduate curricula... New technologies together with advances in the cognitive sciences may soon provide opportunities to develop learning environments that are more tailored to individual teaching and learning styles. In essence, through technology we may reorient our mass production, lecture-driven curriculum to one focused on individualized, discovery-oriented learning. Especially important are initiatives that encourage innovations involving both state-of-the-art laboratory equipment and instrumentation.
>
> —*America's Academic Future. (Presidential Young Investigator Report, NSF 91-150).*

Controls and Alarms. Light switches, thermostats, telephones, vacuum bottles, and piped laboratory services are a few of the many controls one encounters in modern laboratories. Access regulations that predated the ADA have resulted in some of these being routinely located within accessible reach ranges, but not all of them have been addressed. Designers must keep accessibility in mind when specifying not only mounting heights, but also the fixture types, legibility of information associated with such controls (e.g. gas nozzle handles) and required operating pressure. Safety and fire alarm systems fall into this category, and are covered in Parts 4.27 and 4.28 of the ADAAG. Beyond building-wide systems, however, alarm systems built into items of equipment must be reviewed for their degree of accessibility as well.

One last consideration is that, in the process of making a place or item accessible for a certain portion of the population, your designs should not make the use of a facility or item more difficult for able-bodied persons. As noted earlier, many examples of sensible design should benefit everyone, and may also not involve any additional expense.

Conclusion.

In the curricular planning that served as the foundation for your facility planning, you anticipated changes in program that affect decisions about building infrastructure. Remember to design for tomorrow, not for today (even though what will be required in the future is not yet clear). Your aim should be optimum flexibility and adaptability, thus wherever possible, space should be allowed for future duct and piping risers, and for installation of additional equipment, including that for audio-visual and information technology. Demands on science buildings change quickly (sometimes the programmatic requirements change even between the time the design was approved and the dedication of the building). Plan the organization of building systems so that needed changes can be made with ease, including sufficient spare capacity in all areas to handle minor renovations.

Your goal should be to provide the appropriate adaptability for your spaces, balancing cost and performance over the life of building.

CHAPTER VII: SPACES THAT WORK

A learning space has three major characteristics, three essential dimensions: openness, boundaries, and an air of hospitality. When we understand what each of these means, we can find specific methods to create the space for learning.

—Parker Palmer, To Know As We Are Known.

Introduction. A structure for science should speak about openness and teamwork, about being comfortable with "high-tech" and with community. It should be honest and practical about its purpose and demonstrate clearly how it serves that purpose. Your challenge is to design and build spaces and structures that encourage and enhance a vibrant natural science community, where students can be captured by the wonder of doing science and start to think like scientists, where students gain the skills and understandings necessary for productive lives and careers in the years ahead. Such spaces and structures also need to provide a rich environment in which faculty can pursue their own scholarly interests, and be able to translate their research activities into productive learning experiences for students.

◆

Upon entering, everyone should experience what the building is about, what the community of science is about.

◆

Upon entering, everyone should experience what the building is about, what the community of science is about. There are many ways to accomplish this: providing wall space for two- and three-dimensional displays of research results, tackboards for posters from classes, and/or blackboards outside of classrooms and offices (or on the outside of the building!). Spaces can tell stories about the doing of science by incorporating displays of scientific apparatus in an atrium or corridor, or by artwork on floors, walls, and ceilings. Laboratory spaces can be visible, to give direct evidence that the nature of doing science is investigative, hands-on, collaborative, intriguing passersby, students and prospective students, and faculty colleagues about the nature of science.

Spaces that work recognize that learning takes place throughout the building: in the hallway between classes; in the library alcove; at the lab bench doing individual research; in the departmental offices talking with faculty, support staff, and other students; in the computer center during the late night study hours; as well as in classrooms and labs. To attract students to disciplines with the reputation of being difficult, forbidding, and impersonal, such spaces provide a humane environment, one where students feel welcome to take an active role and become personally involved in a true intellectual community.

WHAT WORKS: THIS OLD MATH-HOUSE

The University of Kentucky Story

Design doesn't always need to be brand-new and state-of-the-art to foster new goals of enhancing undergraduate education. In fact, the best design might be an old house.

The University of Kentucky's Mathematics Department sought to foster a supportive community of learners among talented first-year calculus students who are at risk of failing for lack of encouragement or identification with the material. Called "MathExcel," the program is based on Uri Treisman's work with "learning communities"; it targets women, minorities, and students from smaller and rural school districts, recognizing these students are often underrepresented in majors requiring calculus.

While driven by wishes to succeed, the students in MathExcel faced high social hurdles that may have turned them away from mathematics-related disciplines, or perhaps from college entirely. The hurdles perhaps included isolation on the campus, isolation from friends and family, isolation in large college introductory courses, not to mention the standard difficulty with new material. The math department wanted to make a community—to foster in these students a sense of closeness with each other, closeness to the department, closeness to the material and mathematics-dependent disciplines, all through how the course was taught and where the learning took place.

What better way to foster community, really, than to put an aspect of the program into a building made for a close-knit community? Why not an old single-family dwelling? A house is designed with certain social relationships in mind: a common ground floor, each room of which is made for a different social interaction and fosters an informality and intimacy impossible for a classroom and a second floor with private rooms perfect for offices for the program's specially trained teaching assistants.

The department located, repaired, and prepared an old university owned house on campus (professors did renovation work themselves) and gave each student the access code to enter it at anytime she or he wished. Students live in regular student housing, but the Math House is open to them for studying, conversing, and socializing with their friends in the program and/or willing teaching assistants. Students in the program participate in nonjudgmental, pass/fail credit, uncompetitive workshops in the Math House three times a week for two hours each meeting, and work in groups of two to four.

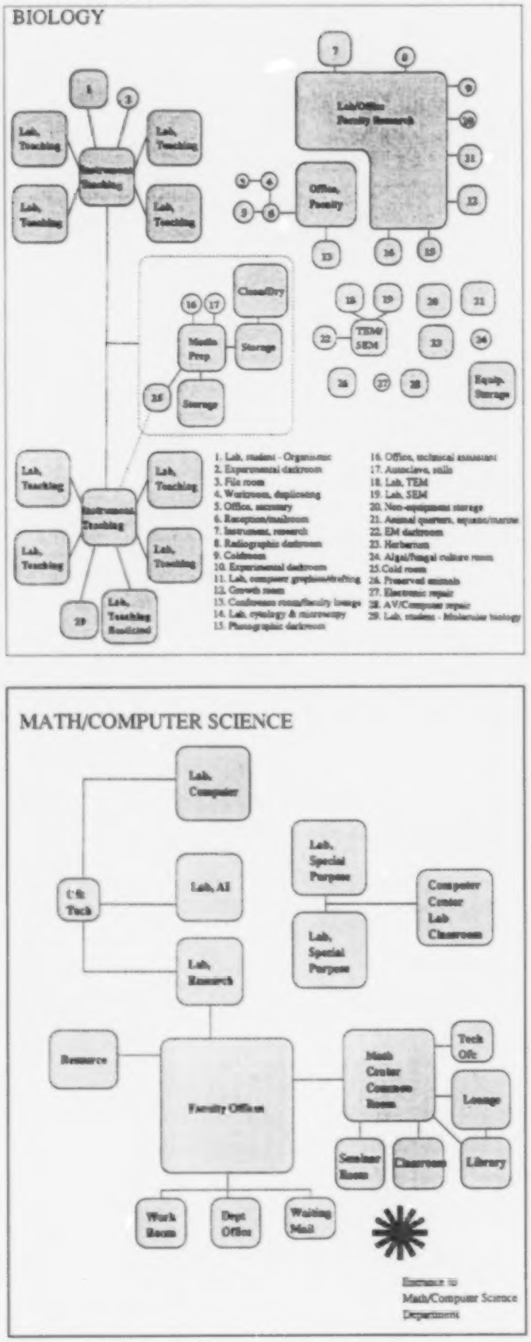
The Math House, as a structure, serves as a kind of teacher itself. The relationship of educational program to space is here all too plain: to foster a community of learners—a facility in which students could be informal was what made the community possible. In a sense though, the Math House did more than that since the program is not for just any student's enlightenment in mathematics but designed specifically for students who have traditionally been left one step outside of the discipline. It serves double-duty, making the foundation upon which the students may be confident about regular university calculus courses and also providing them with workshops and a tightly webbed network of professors and assistants to assure their success in mastering the course materials. Past program participants have been invariably at the top sections of first-year calculus. Program students study together for other courses and tend to stay together after the first year, just like any other group of students united by sharing a living space like a dorm room or dorm corridor. MathExcel leaders report late night telephone calls from these students and recognize other familiar voices in the background—an *ad hoc* study group eating pizza and calling with a question!

Spaces for Community. The various photos and floor plans presented throughout this Handbook suggest different ways to provide both formal and informal spaces for community for undergraduate science/math programs. Such spaces need to be programmed from the very beginning, with particular focus on common spaces (which can escape the attention of departmental committees); this is one place the leadership of the project shepherd can play a significant role. Stairways and balconies, atriums and entry porches, alcoves between offices and labs provide space for communities—of two persons or more. For a community to work, spaces in which individuals can contemplate, study, and do investigative work alone, free from distraction, should also be provided.

The importance of the opportunity for dialogue and discussion within the natural science community on your campus relates both to the centrality of interaction to the process of research and to an understanding of the best pedagogical approaches for today's students. The relationship of offices, laboratories, common areas, and traffic patterns promotes such interaction.

Formal interaction within the lab is important both for safety and the exchange of information and ideas; the placement of benches (and utilities), doors and windows and discussion areas all shape the nature of the dialogue (and therefore of the community) within a laboratory. Formal interaction within the classroom is shaped by the decisions you have made about flat or tiered floors, fixed or movable chairs and tables.

Faculty offices together in an office tower support community in one way; offices scattered through the research and teaching spaces, perhaps linked to student research spaces, are another approach to fostering community. The location of areas for coffee and cookies and for distribution of mail and even the location of the restrooms (although probably not given serious consideration in earlier discussions about mission) affect how the spaces shape the community or communities that use them.



Adjacencies

Community spaces may be more than for majors or faculty in the disciplines housed in the new facility. A new lecture hall or computer laboratories available for use by departments from all parts of the campus can help break down barriers between the disciplines and reinforce the understanding that new facilities for science do contribute to the larger good of the community.

Earlier discussions about traffic patterns on your campus (in considering sites for a new building or making major renovations to an existing building) help determine how to locate the building, its entryways and walkways, so as to provide easy access for potential users and to facilitate the kinds of interactions that are essential for community.

The new spaces and structures for science you are planning need not be major new facilities that house several different disciplines, ones that take a capital campaign to raise major gifts and grants. Sometimes, as illustrated by the story about the University of Kentucky Math House and the earlier stories about renovation projects, spaces that foster the kind of community you desire can be created at modest cost in existing buildings.

CONNECTIONS FOR COMMUNITY: THE ATRIUM

The Susquehanna University Story

This is a story about how the architecture of a science building shapes both education and a community. We don't believe it is mere coincidence that science enrollments at Susquehanna have more than doubled since 1988 (the year that planning for the new facility began).

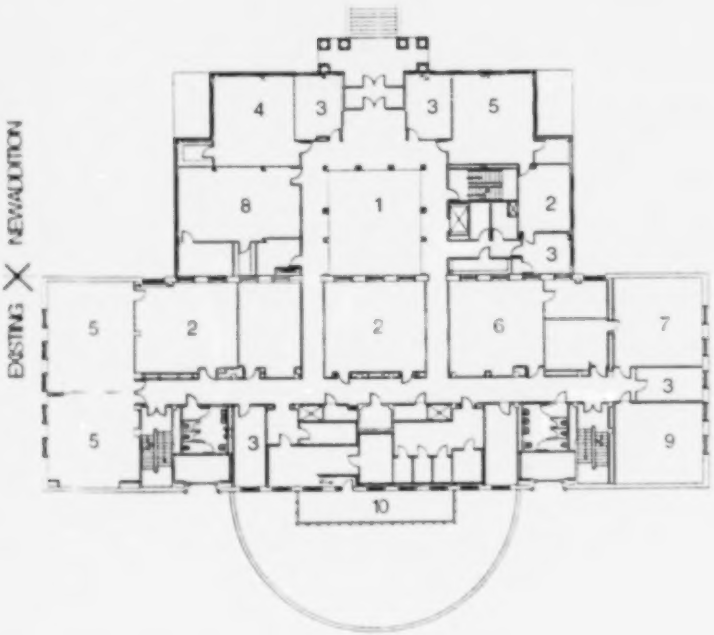
The Fisher Science Hall is a graceful redbrick building that fits comfortably into a lovely campus. Yet, it is not the exterior that makes the building different. It is the interior. A three-story atrium, student-faculty lounges, and open laboratories have changed the way some twenty or so science professors and a couple hundred students go about the business of education.

At the beginning, the atrium was viewed by some as a space-waster. More laboratories and offices could be crammed in if the atrium had come out. However, the atrium with its balconies has become the locus of change. Professors who didn't often see each other before, now chat up and down and across, between, before, and after classes. An idea kindled by a biology professor and shared with a chemist results in a new biochemistry course. Interdisciplinary programs that never took hold before are finally finding their legs. Sharing how the sciences relate has become a priority. Narrow departmental focus is slowly drifting away.

Want to catch a student who missed class? Wait in the atrium. She will go by sometime soon. Need to set up a department meeting? Professors gather on the balconies between classes. Want to catch your professor? Check the conversation zones in each department. There, students exchange information on their projects, sophomores learn the ropes from upperclassmen. Professors can sip coffee and discuss their field or the latest campus news.

Students with only a passing interest in science sometimes walk through the building and stand in front of the windows to the laboratories, watching their friends do experiments. Science once closed to the outsider is open for all to see. Who knows how many science-phobic students will be drawn to science because they are intrigued by what they see in the labs? Certainly the large number of women science majors—28 percent of first-year science students versus less than 5 percent nationally—reflects the impact of the inviting and supportive nature of Fisher Science Hall, as well as of the activities that take place here.

This did not happen without a lot of thought; the unusual character of the building began taking shape in the context of specific educational goals. Professors, students, and administrators met regularly with the architect to discuss their needs, concerns, and dreams. It was in these planning sessions that educational decisions were made that have improved the study of science at Susquehanna. Chemists and biologists together designed a biochemistry laboratory suite—a facility not often found on a campus of under 2,000 students. Professors chose to share research laboratory space with students—a decision that has proven to have symbiotic advantages both for students and teachers—but we knew that would happen.



Second Floor Plan—Entry Level

1. *Atrium*
2. *Lab*
3. *Office*
4. *Physiology*
5. *Biology*
6. *Ecology*
7. *Embryology*
8. *Biochemistry*
9. *Student zone*
10. *Greenhouse*

View of lab.

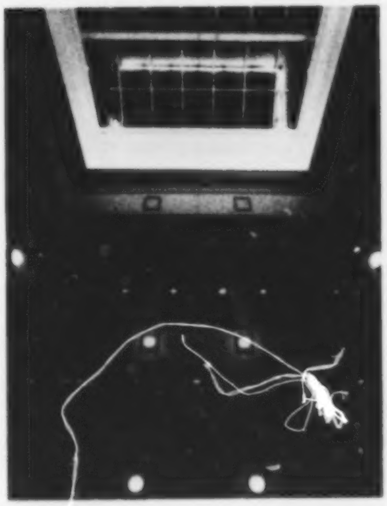
ments, however, is lively. Psychology, biology and biochemistry share an animal research facility. Throughout both new and renovated space, laboratories have been opened to interior view with large windows; faculty and students can interact easily, not only on a given floor, but between floors.

Where the old building was nondescript, the new Fisher Hall is a proud Georgian building at the center of the campus.

Perhaps most importantly, the science building has become an active "hub" of campus activity beyond the sciences themselves. Four general-purpose classrooms were deliberately included in the design of Fisher Hall, where not only science lectures but classes in many other disciplines are scheduled, and the atrium is often used for receptions when classes are not in session.

Results

The building fits into this Georgian campus and reorganizes pedestrian circulation. Major north-south and east-west paths now cross in the atrium, adding liveliness and excitement and providing the opportunity for chance meetings that encourage interdisciplinary dialogue.

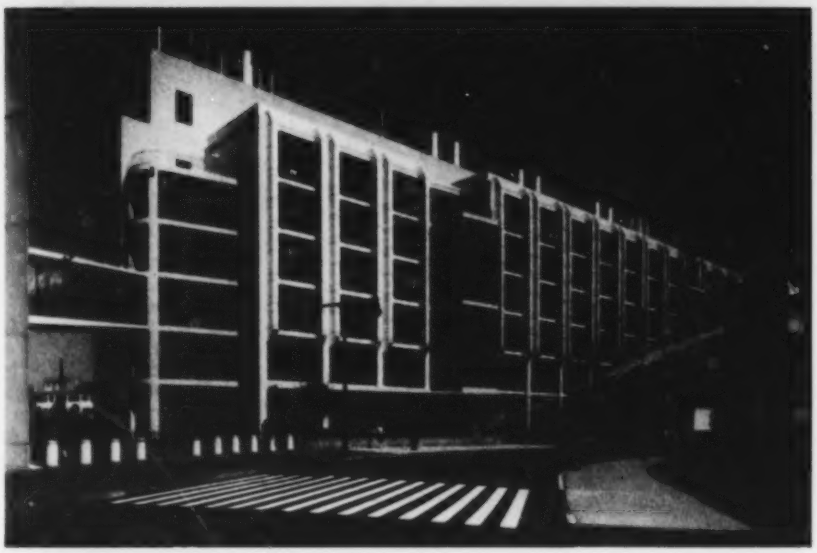


View of atrium.

Massachusetts Institute of Technology

Cambridge, Massachusetts

Architect:	Goody, Clancy & Associates Boston, MA
Size:	252,000 GSF
Construction Cost:	$53,113,000
Net Square Feet:	
Laboratories	51,450
Office, Administrative	24,275
Lab Support	31,350
Seminar, etc.	7,650
Annual Faculty	28,700
Other	3,825
Total	147,250
Completion Date:	June 1994



The MIT Biology Building. The projecting glazed elements are multistory lounges and seminar/break rooms. Vertical metal enclosures on the facade contain fume hood exhausts.

At first phase of the northeast sector of MIT's campus, the new building serves as the headquarters for MIT's Biology Department, and provides state-of-the-art facilities for the teaching and research of biology, microbiology, biochemistry, transgenices, and molecular biology. Five floors of laboratory, laboratory support spaces, and faculty offices are complemented by three levels housing administrative offices, assembly spaces, teaching laboratories, and animal facilities.

Visibility from floor to floor and across the building places the vitality of the building's activities on view.

Design Process

The architect's design team engaged MIT in a multifaceted interactive process. Multiple meetings were held with the faculty committee, physical plant, campus planning, safety, and environmental medicine representatives to refine and review the design. The architects led two series of focused meetings with each individual faculty member, and full-scale mockups of typical laboratory configurations were constructed. From the outset, the principal goal of the building design was to create an environment which would bring together the formerly dispersed department and foster cross-fertilization among students, faculty, and staff.

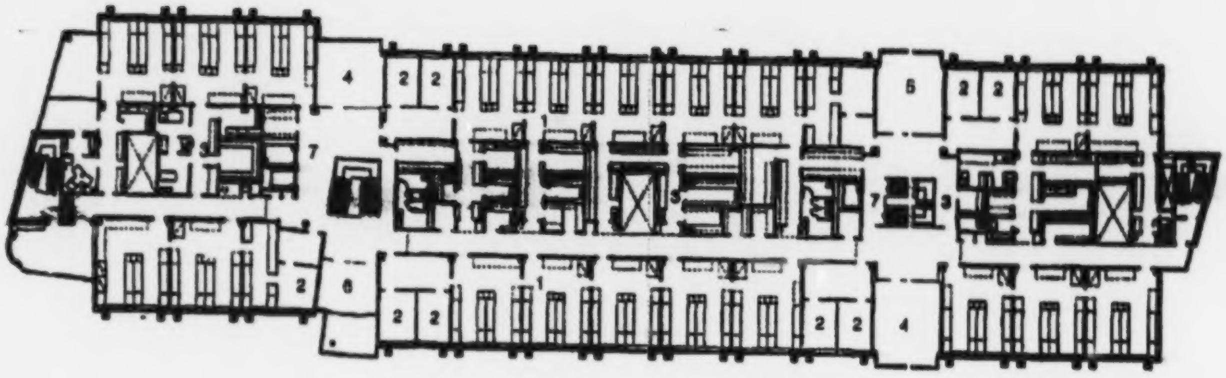
Encouraging Interaction and Community

The floor layouts of the building are designed to enhance communications among research groups. By grouping faculty offices, glass-walled lounges and break rooms, faculty offices, water foundation, toilet rooms, elevators, and generous open stairways at the two full-height atria, opportunities for chance encounters between occupants of the building are increased. Visibility from floor to floor and across the building places the vitality of the building's activities on view.

Glazed doors are used at laboratory entrances, permitting views into and from the labs and across the building. Finally, lounge areas at both ends of the building, enhanced by abundant daylight and informal seating provide further opportunities for impromptu discourse.

Flexibility at Many Levels

The laboratory floor plan is based on a lab module which can be modified to suit a variety of research activities. The laboratories line the exterior walls of the building to take advantage of daylight and views. This perimeter zone also contains offices, and the down-feed utility infrastructure permit easy modification without disturbing adjacent occupants. A highly efficient, single-corridor scheme is utilized, with instrument rooms in the central shared equipment zone serving also as cross-corridors. The placement of fume hood exhaust risers on the exterior facade, concealed by prefinished metal enclosures, removes what would otherwise be obstacles to future change, and minimizes duct crossings within limited floor-to-floor dimensions. Each of the nearly 150 hoods has its own riser which leads to an exhaust manifold in the mechanical penthouse. This manifolded exhaust approach permits the use of glycol-based heat recovery, provides redundancy and improves occupant safety. Six major exhaust fans are utilized instead of the tradi-



Typical Laboratory Floor Plan

1. *4-person modular lab*
2. *Faculty office*
3. *Lab support zone*
4. *Break room*
5. *Conference room*
6. *Lounge*
7. *Atrium/lobby*

tional one-hood-one-fan approach, thus simplifying maintenance and operations. VAV air supply and exhaust systems were designed to facilitate the addition or deletion of a fume hood in any laboratory without the need to shut down or rebalance the entire system.

Hands-On Experience in Classrooms and Laboratories

With biology a required part of MIT's core curriculum, the new facility serves hundreds of undergraduates per year. Two major classroom/seminar spaces on the first floor of the building are employed in conjunction with the largest life-science teaching laboratory on campus. This laboratory accommodates up to 64 students at a time, and is equipped not only with sophisticated scientific and support equipment, but with a wireless microphone/PA system to ensure that the instructor can speak and be heard with ease. Paired with the teaching laboratory are two project labs, in which undergraduates gain direct experience with the laboratory techniques employed by researchers elsewhere in the building, and through the biomedical industry.

Open stairs connect all seven floors of the Biology Building. Glass-fronted meeting spaces bring daylight into the atrium, and faculty offices are located nearby.

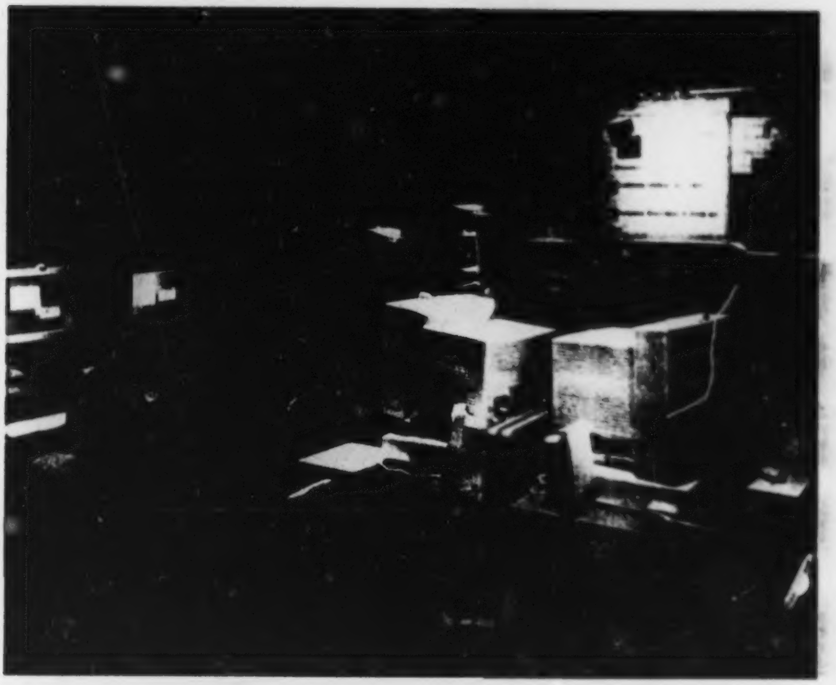
THE MULTIMEDIA CLASSROOM

The Duquesne University Story

The story of the new multimedia computer classroom in the School of Education is not a story about computers but one about teaching. In this classroom, faculty have the capability of teaching everything from music to mathematics, English to entomology, by delivering interactive multimedia material to each desktop. This is possible because the computer staff at the university and the architects worked closely together to transform a traditional 1930's 800 square foot classroom into one that anticipates the 21st century learning environment—and did so in the most cost-effective manner!

The flexibility of the workstations is the key to the success of the classroom. Work surfaces are designed to be able to move quickly into new arrangements during and between classes; constraints associated with the extensive wiring needed for computer classrooms have been eliminated by using an innovative standpipe. Workstations can pivot into a variety of groupings for large lecture seating, small group discussions, cooperative learning groups, or individual work.

Each of the 24 workstations in the classroom contains electrical and data communication connections in a flat box attached to the underside of the work surface. Level 5 UTP (untwisted-pair) wires run into a standpipe that is bolted to the floor. A 2 1/4" raised floor system was specified to accommodate wire management as the existing floor was solid concrete. The installation of the raised floor cost only $11/SF. Using a product called intercell, the raised floor is installed as a series of inverted plastic cones attached to metal plates. It is used in conjunction with easily removable carpet tiles. This makes the floor lightweight and easy to install and allows the height needed for cabling beneath. From the standpipe the UTP wires ran to the maintenance closets.



The cost for the entire project was $200,000, half of which is for computer equipment. The project took only four weeks from start to finish to completely strip the former 45-seat classroom, install the workstations, floor and ceiling and rig the date communications wiring.

The classroom both supports and illustrates the best use of technology in education—for both students and faculty. It is responsible, we believe, for widening the horizons of professors who had not had previous exposure to using computers in the classroom. It is an approachable and unintimidating environment for teaching, as well as for learning.

The benefits of this classroom go beyond the physical campus. Through a partnership with a local private high school, their students can take college-level courses remotely, via video, computer, and telecommunication links.

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Classrooms. Classrooms are some of the most critical spaces in a science facility. This is where the first, and possibly the most impressionable, contact with students occurs; classrooms set the tone for how students interact with the instructor, student colleagues, and with the subject to be taught. *Classrooms that work* happen as a result of thinking first about how you intend to teach.

Most facilities include a variety of classroom styles, to accommodate different types of courses and sizes of classes. These include:

◆ lecture rooms that accommodate one- or two-way communication between speaker and audience

◆ case study settings that facilitate close interaction with speaker and between groups of students

◆ demonstration classrooms that facilitate live teaching demonstrations by instructor or student

◆ media classrooms that incorporate advanced audiovisual tools along with (or instead of) the traditional chalkboard

◆ electronic classrooms that enable all students to be engaged electronically, promoting classroom interaction.

As illustrated by the floor plan of the Anatomy/Histology Lecture and Laboratory Complex at DePauw University and by stories throughout this Handbook, an individual classroom might incorporate various features of those various classroom types. A checklist for classrooms:

◆ ample built-in chalkboard/markerboards (fixed or sliding)

◆ a fixed or portable lectern, with integrated light and audiovisual controls

◆ fixed or portable demonstration benches, with integral electrical and plumbing services

◆ front and/or rear projection rooms, with built-in projection cabinets

◆ rear projection screens/front projection screens (motorized or manual) with "key-stone" reduction tie-back

◆ built-in video projection with multiple source options

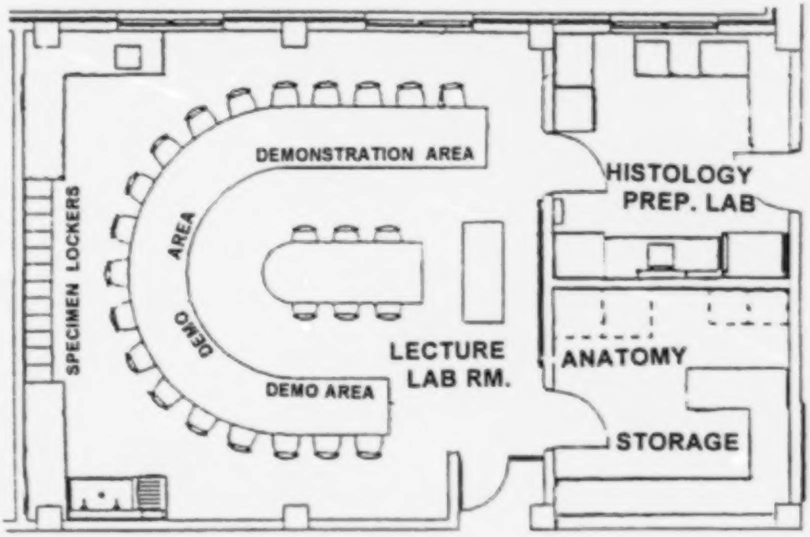
◆ speech amplification and playback amplification systems

◆ audience microphone and/or feedback systems

◆ audience computer power/networking facilities

◆ video recording capabilities.

In your benchmarking visits to other campuses you will have encountered many different styles of classrooms that work. You might also seek advice from colleagues in the humanities and social sciences on your campus, who are often more experienced in interactive approaches to classroom instruction—and who might be joining you in these new classrooms at some time in the future.



DePauw University lecture and laboratory complex.

THE STUDIO CLASSROOM

The Rensselaer Polytechnic Institute Experience

If you step into a classroom and see an energetic and enthusiastic professor giving an animated lecture using projected multimedia controlled from a podium that looks more complicated than the deck of the Starship Enterprise, while students are listening and watching, you may not be in the real classroom of the future. In the real classroom of the future, the positions will be reversed; the students will be the animated and enthusiastic users of multimedia and other networked technologies, while the faculty mentors will be the observers.

The real classroom of the future will probably be more like the artists' studio than like the orator's hall. One cannot imagine real students of art who are content to sit quietly and watch just one person sculpt. Can students of calculus or physics be any different? The results of studies in cognitive science substantiate what most of us know from experience: students learn better from their own efforts than from the efforts of instructors. As a chemistry professor on our campus noted, "Writing the world's best set of notes on the blackboard is not educating—the trick is to get students involved."

Even showing the best set of multimedia notes is not educating. In fact we, similar to other institutions, learned from experience that it can be even worse. Students resented the canned nature of the multimedia lectures and they disliked the darkened rooms required for their projection. We learned that multimedia works best when it is used sparingly during a lecture to illustrate important points with video, graphics, or animation. Even though some students like multimedia used in this "seasoning" way, many of our faculty still felt that we were putting new wine in old skins.

Discussions we had with experts in course innovation from science, architecture, and industry came to a consensus, including the need to reduce the emphasis on the lecture, to improve the relationship between the course and the laboratory, to "scale up" the doing and "scale back" the watching, to include team and cooperative learning experiences, to integrate rather than overlay technology into all courses, and above all—do all of the above while reducing costs! Thus the Studio was born!

What we have done is redesign and deploy new approaches for the curriculum and for the spaces used by the heavily enrolled introductory courses. The approach has been adapted for use in classes in Calculus, Physics, Chemistry, LITEC Engineering, Differential Equations, Dynamic Systems, Computer Science, Biology and other more specialized courses.

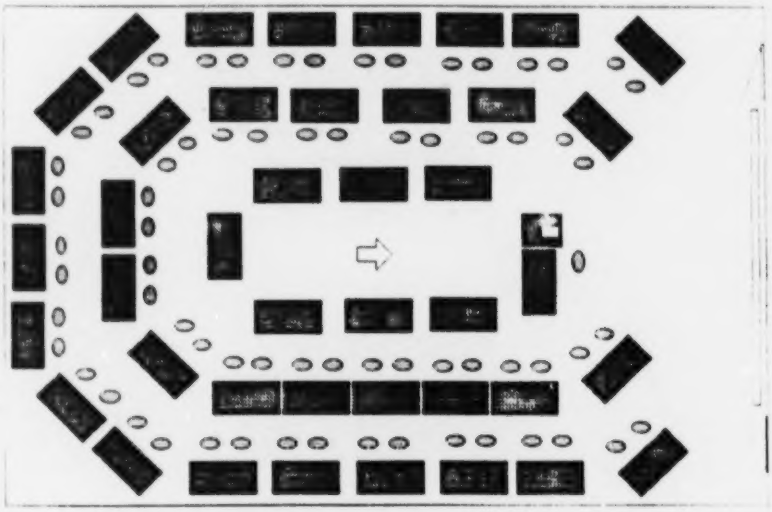
During the summer and fall of 1993, we completely renovated two classrooms for the first offerings of the Studio Calculus, Chemistry, and Physics courses. In these classrooms there are 32 worktables (each designed for two students), an open work space and a computer workstation. The student worktables form three concentric partial ovals around the room, with a worktable for the teacher in the front of the room near the projection screen. The workstations are so arranged that students can turn from the center of the room to work with colleagues on an assigned problem in their own small group; equally important, they are arranged so that the instructor is able to see all workstation screens from the center of the oval, and thus able to keep on top of how students are proceeding.

These physical changes in the classroom have made curricular changes possible. In Physics, for example, the classroom has full access to networked multimedia from CUPLE (Comprehensive Unified Physics Learning Environment from the American Institute of Physics). CUPLE includes microcomputer-based laboratory systems for data acquisition, analysis, and visualization. The discussions are good because, with the semicircular arrangement of chairs, students can see each other with a quick swivel of their chairs.

Our experience with the Studio in Calculus also illustrates the benefit of these new spaces. Calculus students are involved with: *short discussions*—to introduce new materials; *paper and pencil activities*—where students work problems based on the new material; *small group activities*—where students work together to discover concepts and problem-solving approaches on their own; *MAPLE activities*—during which students explore problem-solving approaches, provide on-the-spot reinforcement of concepts, and explore further concepts that help them understand key ideas in calculus; and *peer teaching activities*—whereby students in a group that has mastered concepts presented and discovered in earlier sessions help others "get the point."

The Studio Classroom is user-friendly to instructors who prefer a traditional model in which activities are teacher-centered rather than student-centered. But, as a facility in which the instructors wish to serve more as a mentor/guide/advisor, the Studio is great. Rather than separating the functions of lecture, recitation, and laboratory, the instructor can move freely from lecture mode into discussion, and can assign a laboratory, worksheet, or computer activity without the need to move to another room or spend time moving furniture. With little effort, in the Studio, students can discuss ideas and results with neighboring groups and with the entire class. The space makes it possible to incorporate cooperative learning approaches, and to use the latest computer tools.

The Studio Classroom experience illustrates the close coupling between the design of facilities and the educational models and techniques that can be deployed in the classroom. Through redesign of the space, we have created a powerful link between the lecture, problem-solving materials, and hands-on laboratories, a link that, in traditional courses, is tenuous at best. The most important feature of the Studio is that each student is able to experience an environment for learning that is personal and that provides significant opportunities for collaborative activity. That this approach works is clear from assessment of the courses, which indicates that in spite of reduced contact hours, students in Studio courses were able to complete the material faster than their peers in previous years. From the perspective of both faculty and student, they are an effective and efficient introduction to science.



The Studio Classroom

Teaching Laboratories.

The teaching labs designed today reflect the trend toward truly experimental work at the undergraduate level. Rather than learning that takes place in discrete time periods—using cookbook labs, students now have opportunities for learning that are open-ended, hands-on. This calls for spaces for undergraduate labs organized differently from the spaces built in the 1950's and 1960's.

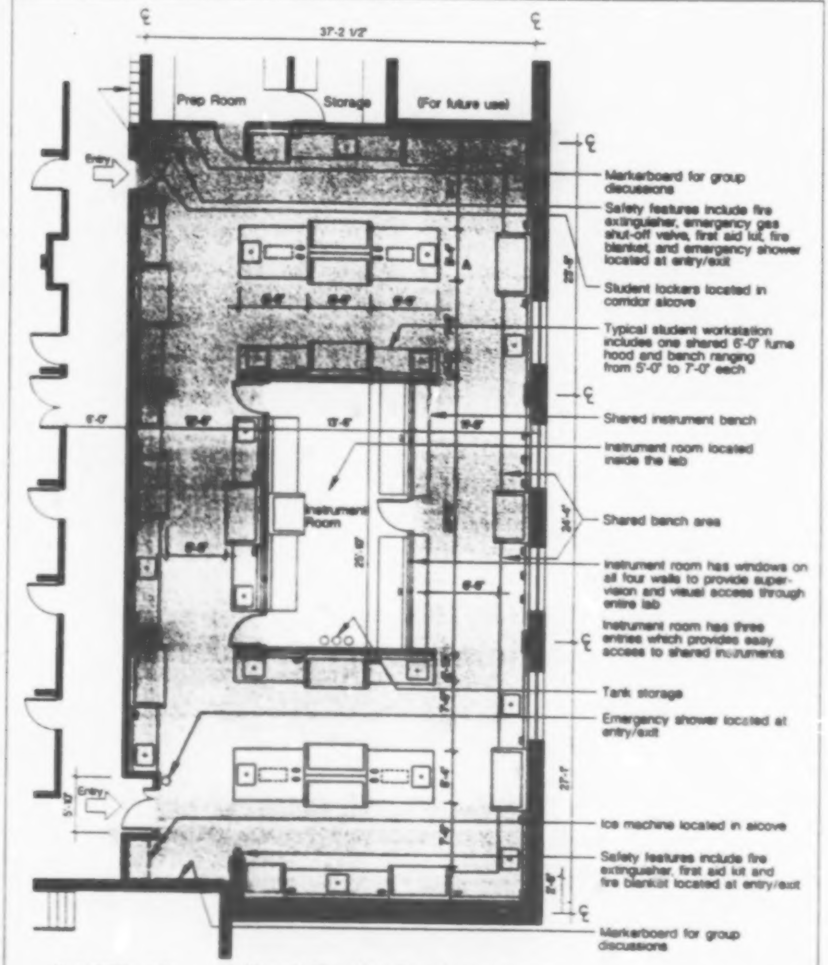
Further, labs today, both for teaching and research, need to be accessible to all students. This means that any new or renovated lab has to be organized so that a disabled student could enroll and succeed in your courses and work toward a degree.

The amount of space required in a teaching laboratory depends upon many factors: the discipline, type of lab, level of course, equipment, teaching methodology, and extent of flexibility desired. The typical amount of net square feet per station required for general introductory courses in the sciences is:

General Biology	**50 NASF to 60 NASF**
General Chemistry	**50 NASF to 80 NASF**
General Geology	**40 NASF to 60 NASF**
General Physics	**40 NASF to 60 NASF**
General Psychology	**30 NASF to 40 NASF**

Although it is somewhat difficult to generalize, designing teaching laboratories based on dedicated student workstations (for example, biology, chemistry, geology and some physics) can be considered from the same perspective, as they have many common features. Other teaching laboratories, such as for psychology, advanced physics, and math and computer science, are more unique in character.

Student Workstations. In designing teaching laboratories, the prime consideration is the total number of student stations to be used on a regular basis. The number of student workstations per laboratory varies, but the current trend favors fewer workstations, with many teaching laboratories falling in the range of 20 to 24 student workstations and introductory courses falling in the range of 24 to 32 workstations. (The design should be flexible enough to accommodate expansion or reduction in the likely event of student enrollment fluctuations.)


37'-2 1/2"
Prep Room
Storage
(For future use)
Entry
Exit
Instrument Room
Markerboard for group discussions
Safety features include fire extinguisher, emergency gas shut-off valve, first aid kit, fire blanket, and emergency shower located at entry/exit
Student lockers located in corridor alcove
Typical student workstation includes one shared 6'-0" fume hood and bench ranging from 5'-0" to 7'-0" each
Shared instrument bench
Instrument room located inside the lab
Shared bench area
Instrument room has windows on all four walls to provide supervision and visual access through entire lab
Instrument room has three entries which provides easy access to shared instruments
Tank storage
Emergency shower located at entry/exit
Ice machine located in alcove
Safety features include fire extinguisher, first aid kit and fire blanket located at entry/exit
Markerboard for group discussions
24'-4"
27'-1"

Scale: 3/32" = 1'-0"

Organic Chemistry Teaching Laboratory

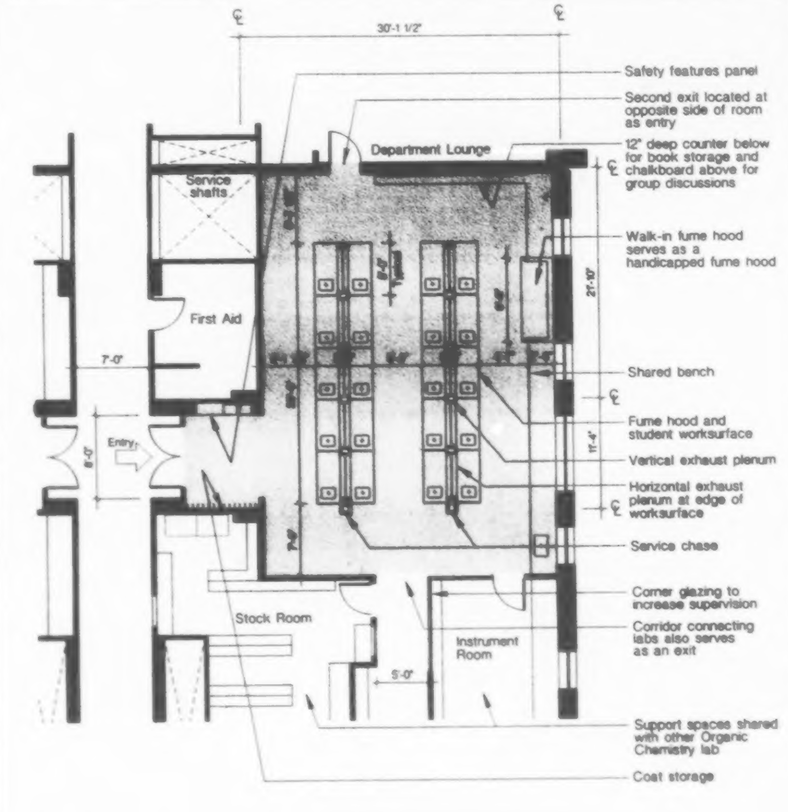
Dedicated "student" workstations, typically found in biology and chemistry teaching laboratories.

often found in geology, and sometimes in physics teaching laboratories, fall within the general range of 36 to 48 inches wide by 24 to 30 inches deep. Student workstations can be sitting-height benches that are approximately 30 inches high, and/or particularly in most biology and chemistry teaching laboratories standing-height benches that are 36 inches high. The current trend is toward more standing-height benches, as they can accommodate more activities than a sitting-height bench and interaction is facilitated. A good quality adjustable chair with back and foot support is required, however, for standing-height benches, so students can engage in activities such as microscopy and dissection with ease.

Shared Benches. In addition to the dedicated student benches, other laboratory bench requirements in teaching labs typically include shared-instrumentation benches for accommodating a variety of bench-top instruments such as water baths, balances, melting point apparatus, etc. (Sometimes such instrumentation is located out of the labs in a shared-instrument room.) This shared bench space is often used for exhibiting displays and distributing materials for use in the laboratory. Shared laboratory benches range anywhere from 15 linear feet to 30 linear feet per teaching laboratory and are often configured as a perimeter wall bench or occasionally as a center island bench.

Fume Hoods. In addition to bench space, many teaching laboratories, particularly those in chemistry, require fume hood space. The current trend is to provide students with more fume hoods, even for introductory-level chemistry courses. For such courses, student pairs typically share a 5' or 6' wide fume hood, in addition to the 3' or 4' bench area provided for each student. Lab sinks are also often shared between 2 and sometimes 4 students in these teaching laboratories.

The most fume hood space in proportion to work area in teaching labs is required for organic chemistry; many colleges/universities request that each student be provided with a fume hood 4' or 5' wide for each bench 3' or 4' wide. Other institutions require organic chemistry courses to be taught entirely within the fume hoods, with each student being provided a 5' or 6' fume hood without adjacent bench space. Alternately, if students



℄
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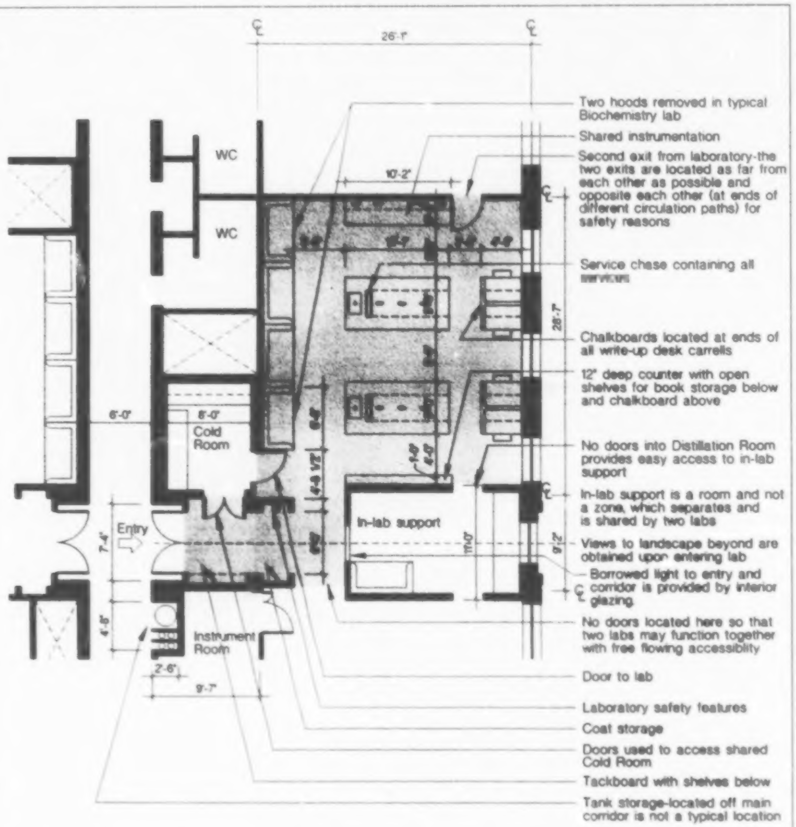
30'-1 1/2"
Safety features panel
Second exit located at opposite side of room as entry
12" deep counter below for book storage and chalkboard above for group discussions
Department Lounge
Service shafts
Walk-in fume hood serves as a handicapped fume hood
21'-10"
First Aid
7'-0"
Shared bench
Fume hood and student worksurface
11'-4"
Vertical exhaust plenum
Entry
8'-0"
Horizontal exhaust plenum at edge of worksurface
Service chase
Corner glazing to increase supervision
Stock Room
Corridor connecting labs also serves as an exit
Instrument Room
5'-0"
Support spaces shared with other Organic Chemistry lab
Coat storage

Scale: 3/32" = 1'-0" **Organic Chemistry Teaching Laboratory** are using microscale they can be provided with down-draft systems at each workstation. Increasingly, as more and more chemicals are being declared hazardous, biology labs will require at least one or two fume hoods. Fume hoods are required less often in physics teaching laboratories and are typically not required in geology and psychology teaching laboratories.

Equipment. In addition to the shared laboratory bench, space for built-in and movable equipment and storage is required for all teaching labs, ranging anywhere from 10 to 20 linear feet of wall space. In-lab equipment includes refrigerators, incubators, and occasionally ovens, with storage cabinets required for demonstration apparatus, display materials, microscopes, chemicals, etc.

Organization. The arrangement of these elements within a teaching laboratory becomes critical as alternative teaching styles are accommodated and if functional flexibility is desired for the foreseeable future (and for the future which cannot be foreseen). The arrangement of laboratory benches and fume hoods is particularly challenging in chemistry teaching laboratories if each student is provided with dedicated fume hood space. For instance, if faculty wish to present prelab lectures with students seated at their workstations in the labs, sightlines to the instructor and teaching wall must be carefully considered. Visual obstructions such as fume hoods or structural columns need to be located on the perimeter to accommodate this teaching style. However, in this situation, the distance between the student bench and the fume hoods may not be appropriate; in fact, it may create an unsafe condition with students traveling the distance between laboratory benches and the fume hoods with chemicals in hand.


26'-1"
WC
WC
10'-2"
28'-7"
6'-0"
8'-0"
Cold Room
Entry
7'-4"
In-lab support
11'-0"
9'-2"
4'-6"
Instrument Room
2'-6"
9'-7"
Two hoods removed in typical Biochemistry lab
Shared instrumentation
Second exit from laboratory-the two exits are located as far from each other as possible and opposite each other (at ends of different circulation paths) for safety reasons
Service chase containing all services
Chalkboards located at ends of all write-up desk carrells
12" deep counter with open shelves for book storage below and chalkboard above
No doors into Distillation Room provides easy access to in-lab support
In-lab support is a room and not a zone, which separates and is shared by two labs
Views to landscape beyond are obtained upon entering lab
Borrowed light to entry and corridor is provided by interior glazing
No doors located here so that two labs may function together with free flowing accessiblity
Door to lab
Laboratory safety features
Coat storage
Doors used to access shared Cold Room
Tackboard with shelves below
Tank storage-located off main corridor is not a typical location

Scale: 3/32" = 1'-0"

Chemistry Research Laboratory

Good sightlines throughout teaching laboratories are always critical, particularly in those that use hoods, so that the instructor can monitor adequately all student activities. Again, fume hoods located on the perimeter with adjacent student benches are a common solution to provide good visual access throughout the laboratory, but these may interfere with windows to the outside, and/or doors to the corridor. Some institutions are using fume hoods with glass panels on all three sides as well as a glass sash, which give increased ability to monitor activities throughout the laboratory.

For reasons of safety, a closer relationship of fume hood to student benches is often desirable in these laboratories, even though this is at the expense of the ability to conduct a prelab lecture visible and audible from the student station. Areas can be provided in front of chalkboards for students to bring their lab stools if "chalktalk" sessions are required within the laboratory.

Occasionally, the noise associated with the supply and exhaust air needed for the fume hoods in chemistry teaching laboratories adversely affects the ability of the instructor to conduct a chalktalk; discussion rooms adjacent to multiple teaching laboratories can provide good locations for uninhibited discussion, thus avoiding noise in labs.

In teaching laboratories laboratory benches are designed to support student interaction. Students working in groups of 2 to 4 learn more effectively than students working alone. Where former teaching laboratories were designed for efficiency with long benches, each able to accommodate 6 to 8 students per side, today's laboratories are more likely to be designed to accommodate 4 to 6 students at a single bench. Laboratory benches which can accommodate such student groups also have the benefit of additional circulation aisles that allow faculty to access the student workstations more easily and thus increases the potential for student/faculty interaction.

The arrangement of student laboratory benches takes many different forms, from more regular orthogonal arrangements to fan-shape and herring-bone organizations. Regardless of the arrangement, sufficient clearance should be provided between laboratory benches. At sitting-height benches, a minimum of 5 feet should be provided; a 6 foot minimum clearance is preferred.

For standing-height benches, a minimum of 4 feet clearance is required, with 5 feet being the preferred clearance. The minimum clearances provide sufficient space for students but may not accommodate faculty access.

In order to achieve flexibility in the planning, design, and occupancy of the facilities, it is common to

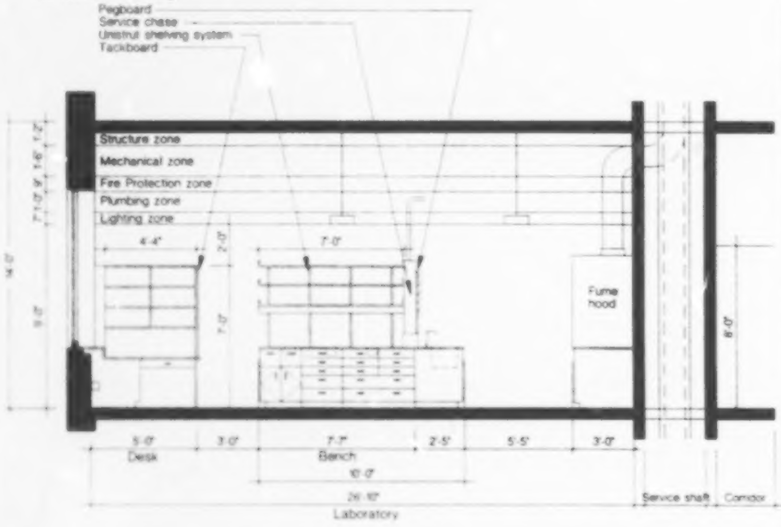
Each student has one bench, one write-up desk and one fume hood
Each bench a workspace of 7'-7" and no knee space
Cabinets under benche consist of drawers and doors
Paired write-up desks are 4'-4" with additional workspace along window wall, creating alcoves opposite island benches
Casework below desk includes pencil drawer only; casework below counter, along window wall, consists of pencil drawer and drawer cabinets
Shelving System at bench consists of:

- L-frame support anchored to floor
- Horizontal Unitrust channels
- Continuous wood beam to support top shelf
- 8"x1" thick, back-to-back fixed shelves with 3"h shelf ends at lower two tiers, creating a continuous 16" shelf surface
- 24"w x 1" thick fixed top shelf with 3"h shelf ends

Shelving system at desk consist of:

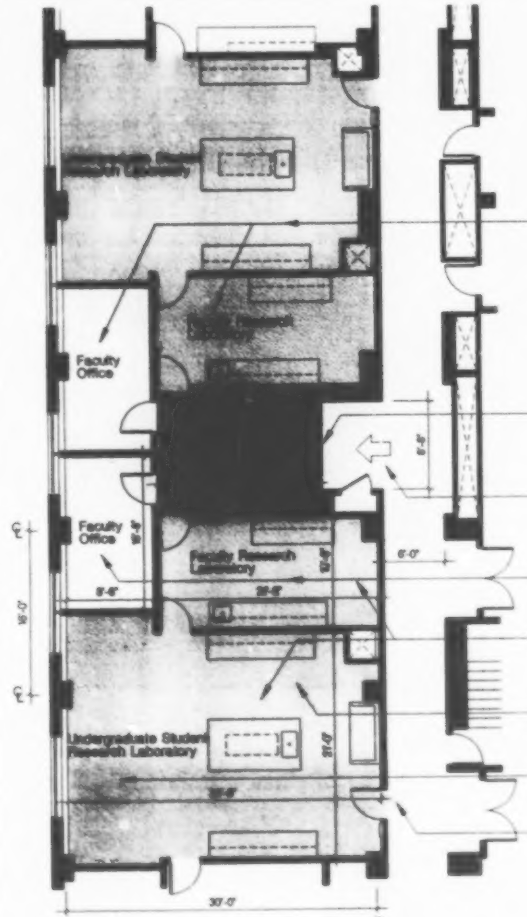
- 1" fixed plywood top shelf
- 1" fixed plywood bottom shelf with 1"x3" apron and task light beyond
- 2 tiers of 1" adjustable plywood shelves
- Adjustable shelf standards and clips at sides of desk shelf unit
- Tack surface covering desk divider surface above countertop
- Tackboard on outer surface of back-to-back desk

No acoutstical celing.



Scale: 3/16" = 1'-0"

Section through Organic Chemistry Research Laboratory organize the building systems and infrastructure based on a laboratory planning module. The planning module width is based on the depth of bench, equipment, or hood space on each side of an appropriate area, and varies between about 10-11 feet in width. The depth of the module varies considerably, depending on the function, occupancy, and furnishings to be accommodated, but tends to be between 25-32 feet in depth. Module depths of less than 25 feet tend to limit the feasibility of furnishings and circulation arrangements. Depths greater than 32 feet present problems with structural spans in trying to maintain a relatively vibration-resistant, column-free environment within the laboratory space.



"Cluster concept" of grouping faculty laboratories and offices with junior and senior student laboratories allows young scientists to work closely with mentors - a unique concept typically associated with graduate students

Lounge designed without doors to encourage informal student/faculty interaction

Main entry into suite

Faculty research laboratories and offices are grouped around central lounge

Faculty laboratory is adjacent to student laboratory in order for professor to provide close monitoring and mentoring

Spacious student research lab supports up to 4 students in independent research conducted under faculty supervisor

Ample space for equipment requirements

Student research lab may be entered directly from corridor

Scale: 3/32" = 1'-0"

Biology Research Suite

Casework and Benchtops. Student laboratory benches are available in a variety of materials, including wood, steel, and plastic laminate casework. Wood casework is most often the preferred material in academic laboratories, due to aesthetics, durability, and ease of repair. Plastic laminate construction has improved in the last few years and is often an acceptable choice in laboratories where physical abuse is less prevalent. Benchtop materials for those sciences using fewer caustic materials can be accommodated with chemical-resistant plastic laminate. Laboratories requiring a more durable benchtop often are fabricated from molded epoxy resin, epoxy-coated stone, or epoxy-coated synthetic materials.

Durability and cost are typically the two issues which have influenced the selection of laboratory bench materials in teaching laboratories in the past. Aesthetics has recently been added to the selection criteria, and bench materials are available now in a myriad of colors. In addition to creating a more pleasant environment, benches of lighter color require less illumination.

Research Laboratories.

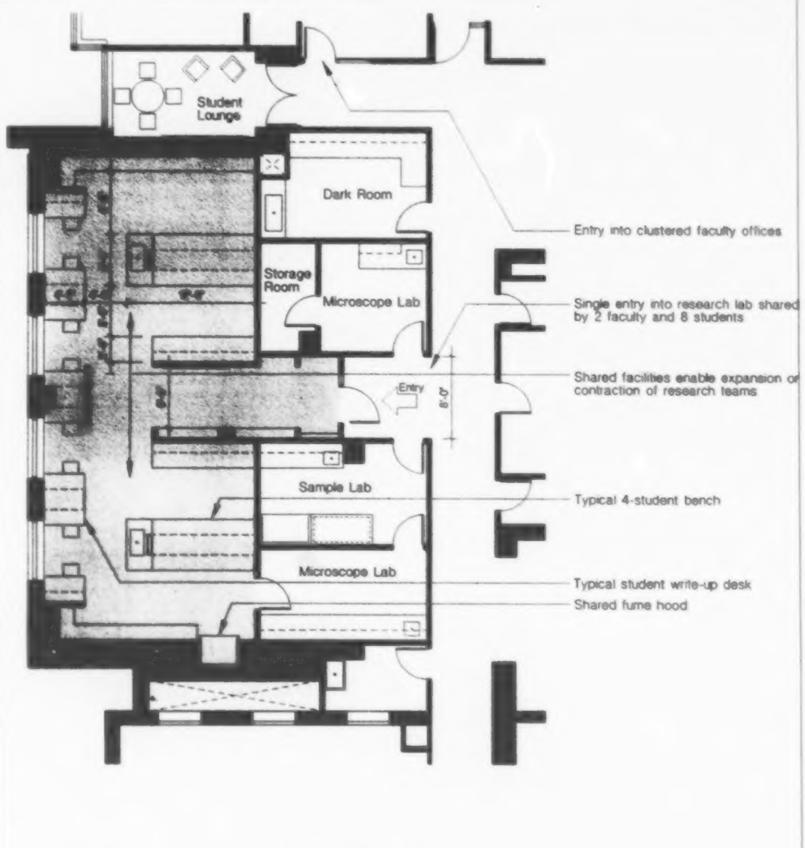
Research laboratories in undergraduate colleges and universities are often provided for faculty and students as a shared laboratory. Some colleges and universities also provide dedicated research laboratories for their students, given curricular requirements for undergraduate research as well as for their faculty to pursue new scholarship. The design of research laboratories is influenced by issues such as flexibility, efficiency, and safety, in the same manner as are teaching labs.

The requirements and configurations of research laboratories vary significantly depending on the discipline. Research laboratories for geology are very different than those required for physics, which again are very different than those required by psychology. Requirements for biology and chemistry research facilities are most similar in that they both require a certain number of laboratory benches and fume hoods in addition to in-lab instrumentation and equipment. Because the requirements of the biology and chemistry laboratories (both research and teaching) are so similar, they are often designed so as to be interchangeable should future departmental directions require such.

The primary differences between biology and chemistry research laboratories are in the number of fume hoods and in laboratory bench heights. A typical shared faculty-student research laboratory for chemistry provides 2 to 4 standing laboratory benches with 2 to 4 fume hoods, each of which are 4 to 6 feet wide, and 2 to 4 student desks with 1 or 2 laboratory sinks. A typical shared faculty-student research laboratory for biology would provide the same elements, except some of the laboratory benches may be sitting-height, and only 1 or 2 fume hoods may be required. In place of the fume hood, however, a biological safety cabinet may be required, as may additional refrigerators, freezers, or incubators.

Laboratory benches for research labs are often 8' to 10' long, being typically 30 inches deep if located on the perimeter as a wall bench and 5' if organized as an island or peninsular bench. Fume hoods are always located away from major circulation aisles, and dead-end aisle configurations are discouraged. Some codes require two means of egress from a laboratory. It is acceptable that one access through an adjoining room. Whether required by code or not, a second means of egress is good practice in any laboratory which utilizes hazardous materials.

The second means of egress with such an organization can be provided through an adjacent research lab. Clearances between laboratory


Student Lounge
Dark Room
Storage Room
Microscope Lab
Entry
8'-0"
Sample Lab
Microscope Lab
Entry into clustered faculty offices
Single entry into research lab shared by 2 faculty and 8 students
Shared facilities enable expansion or contraction of research teams
Typical 4-student bench
Typical student write-up desk
Shared fume hood
Scale: 3/32" = 1'-0"

Biology Research Laboratory

benches in research labs are similar to teaching laboratories with 5' being preferred clearance for standing-height benches and 6' being the preferred clearance for sitting-height benches. Laboratories with fume hoods should provide a minimum of 5' clearance in front of fume hoods.

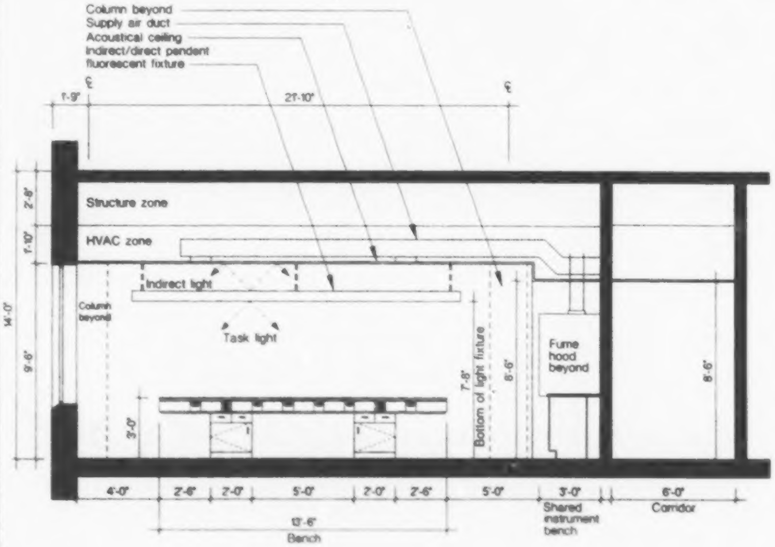
Although a typical shared faculty-student research laboratory for the disciplines of biology and chemistry can accommodate 2 to 4 students, many colleges/universities see the benefit in providing multiple contiguous research laboratories. Contiguous labs also provide both an opportunity for additional interaction between research groups and flexibility should one research group require additional space.

The requirements of research laboratories for physics, geography, psychology, and math/computer science are much more diverse, but certain planning principles still apply. For instance, these research laboratories should be designed to accommodate the anticipated number of individuals but should also be arranged to allow flexibility both in terms of the number of individuals accommodated as well as the functions and activities to be accommodated.

Each lab consists of three 8-student island benches, one fume hood, and one wall bench.
Cantilevered ends of benches, in lieu of legs, generate flexibility which allows students and faculty to group at ends without obstacles. The need for several pieces of equipment at each bench at any given time promoted the need for:
- flexibility
- unobstructed bench surfaces
- continuous electric wiremold and data raceway located along rail below the countertop

Rail below countertop is 8" thick in order to:
- support cantilever
- contain electric wiremold and data raceway

Teaching aids include markerboard and shared instrument bench
An important goal was to design an open and light lab by using:
- suspended pendant lighting consisting of:
  - direct task lighting over student benches.
  - indirect lighting reflecting off ceiling
- gray epoxy countertops
- light colored oak casework



Scale: 3/16" = 1'-0"

Section through Biology Teaching Laboratory

Flexibility can be achieved in physics research laboratories by providing generic services such as electrical power, air, vacuum, and occasionally gas along various points on the perimeter wall, leaving most of the laboratory benches movable to accommodate a variety of set-ups. Flexibility can be accommodated in geology laboratories by selecting a laboratory module size that can accommodate a variety of activities, furnishings and equipment including map cases, rock cabinets, light tables, drafting tables, etc. Finally, flexibility can be achieved in psychology research laboratories by considering shared laboratory facilities that can accommodate a variety of functions.

Customized research facilities for individual faculty members should be avoided if at all possible so that changes in faculty do not necessarily require facility modifications.

Adjacencies. An aspect of laboratory design that has significant impact on the way the facilities function is the arrangement of the laboratory facilities in relation to other instructional spaces such as support spaces, seminar rooms, classrooms, study rooms and discussion rooms, and offices and workrooms. One advantage to locating research laboratories adjacent or contiguous to teaching laboratories is the ability to share support spaces such as instrument rooms, equipment rooms, prep rooms, stockrooms, storage rooms, and other specialty rooms including animal facilities, electron microscope labs, and tissue culture labs.

The integration of research and teaching now common in undergraduate programs also suggests these spaces should be grouped in similar areas of the building. Some institutions leverage their use of space by expanding research activities into the teaching laboratories during nonacademic periods of the year. If so, grouping spaces with the most intense mechanical, electrical, and plumbing requirements in a single part of a building can reduce construction as well as operational cost.

As mentioned above, the relationship of faculty offices and teaching and research laboratories can take many different forms. Some colleges and universities prefer to locate faculty offices adjacent to laboratory facilities so that interaction is facilitated between students and faculty. The other extreme is to locate all faculty offices in one area so faculty, across disciplines, programs, and departments, have significant opportunity for interaction. Certainly, there are several models that take the middle ground by creating pods of faculty offices distributed throughout the laboratory facilities. Issues such as student-faculty interaction, faculty-faculty interaction, construction cost, and operational cost should all be considered during the discussions of these adjacencies.

For Issac Newton, truth was "offspring of silence and unbroken meditation." Sir Isaac might have felt out of place in Dartmouth College's new chemistry building.

The $26-million Burke Laboratory goes out of its way to discourage monkish isolation and encourage "interaction," "the sharing of ideas" and "unplanned encounters."

...To help the intellectual sparks fly, Dartmouth now requires professors from different chemical disciplines to cluster their offices together. "I'm talking to more people than ever before," says an inorganic biochemist who finds herself housed close by an organic chemist and two physical chemists, one experimental, the other theoretical.

To encourage hall encounters, offices are separated from labs...[with] a lounge with a kitchen, and a three-story open staircase wide and grand enough to create another meeting space.

But Burke's real innovation in togetherness is the "write-up rooms" next to its laboratories. Dartmouth researchers used to write up their experiments and meet visitors in the tense, toxic environments of their labs. Now they can remove their safety goggles, write, meet people, even eat a sandwich at desks separated from their experiments only by safety glass.

...the Dartmouth building is part of a broader movement toward academic buildings designed to promote interaction. "These are not frill spaces...Their function is to get people together, and their symbolism is the university as a place where information is shared."

—*Wall Street Journal, September 30, 1992.*

SPACE UTILIZATION FOR RESEARCH

The Morehouse College Experience

The design of the biology curriculum and research laboratory facilities at Morehouse College reflects our philosophy that research is an integral component of undergraduate education. Biology majors are required to take three biology laboratory courses beyond the first-year course in general biology. In addition, students can receive credit for conducting independent research in the laboratory of a faculty member.

We began a critical revision of the biology curriculum in 1987 at the same time that new physical facilities were being developed. In 1990, new laboratory courses were implemented in biochemistry, physiology, and molecular genetics. Laboratory courses in cell biology, plant sciences, and ecology were added to the core curriculum in 1993. In addition to the core requirements, we decided to offer a sequence of elective courses where students could receive up to six hours credit for doing research under the supervision of a faculty member in the department. The first course in the sequence is a one hour lecture course primarily for freshmen which aims at familiarizing students with scientific writing and reporting. The second and third courses in the sequence, worth two and three credit hours respectively, require that students perform research in the laboratories of faculty members.

It was clear that we needed more space in order to implement the new biology curriculum, and, thus, we began to push for a new biology-chemistry building that had been on the drawing board for a number of years. The Nabrit-Mapp-McBay Science Building was completed in 1989 and included research laboratories for four biology faculty and two instructional laboratories.

The growth in the department during the last few years led to the development of a proposal which was funded by the National Science Foundation to renovate Hope Hall, the old biology building at the college. The total renovation of the Hope Hall Science Building at Morehouse College has provided the Department of Biology with modern, flexible, and safe research and teaching facilities for faculty and students. The seventy-year-old Hope Hall has all but ceased to meet the needs of the Department of Biology as the faculty actively pursued research in very diverse fields: molecular genetics, cell biology, cell membrane physiology, plant sciences, and behavioral ecology, and as stated above, the undergraduate curriculum evolved with increased emphasis on laboratory and research experience. Five faculty research laboratories and connecting offices are relocated on three floors. Faculty offices have dual entrances from the hallway and from the laboratory. Each research laboratory was designed with the objective of meeting current need while maintaining flexibility to meet the changing needs of the future. Student desk space is part of the permanent furniture-cabinet work in each faculty research laboratory. Three instructional laboratory facilities are located on the second and third floors. These instructional laboratories are used by six upper-level biology laboratory courses during the academic year (molecular genetics, biochemistry, physiology, cell biology, plant sciences, and ecology). In the summer, the instructional laboratories are available for student research. Research-support facilities are located throughout the building. A centralized (second floor) equipment room contains an autoclave, ice machine, freezers, dishwasher, and an oven. An electron microscope suite (first floor) houses scanning and transmission electron microscopes and contains facilities for specimen preparation and a darkroom. Animal-holding facilities for small laboratory animals and for aquatic organisms are in three interconnected (first floor) rooms. Two separate laboratories are dedicated to soil preparation for plant sciences work and to heavy metal (pollution) analysis with an atomic absorption spectrophotometer. A biostatistical research laboratory (second floor) contains twenty-five microcomputer stations for research data analyses, mathematical modeling, and research related computer processing. Adjacent to the building is a newly completed 1,560-square-foot greenhouse facility which is used for student and faculty research and preparation of course materials for the plant sciences and ecology laboratory courses.

A WELCOMING ATRUIM

The Colorado College Experience

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RESEARCH AND TEACHING LABS FOR BIOLOGY

The Harvey Mudd Story

The Olin Science Hall at Harvey Mudd College, completed in spring 1993, was designed to house two new departments, biology and computer science, and to provide new quarters for the mathematics department. The nature of the program drove our planning for the facility: while mathematics and computer science needed mostly offices; the biology space needed to provide both teaching and research laboratories as well as offices.

A major need for the biology department was spaces for student/faculty research labs to complement the normal teaching laboratories. At Harvey Mudd, it is expected that our students will be heavily involved in independent work, especially during their senior year. This work is either in what we call the "clinic," where students work in teams on real-world projects sponsored by a range of companies, or in research under the guidance of a faculty member. Thus, six relatively large research labs and three teaching labs, all specific to the nature of our program, were developed.

On the lower floor of the building are the teaching labs. One is an introductory lab which includes an adjoining space for microcomputers. A second is a neurobiology lab with six neuroworkstations with digital imaging capability; courses such as neurophysiology, biological imaging, and portions of junior laboratory and introductory laboratory are taught in this lab. The neurobiology lab is particularly flexible, with space for the imaging and neuroworkstations, for tabletop work, and for discussion/seminar activities. In addition, very little of the workspace is built in so that the lab may be reconfigured as desired. The third lab, for cell and molecular biology, is where courses such as molecular evolution, developmental biology, biology of prokaryotes, and a portion of the junior laboratory are taught.

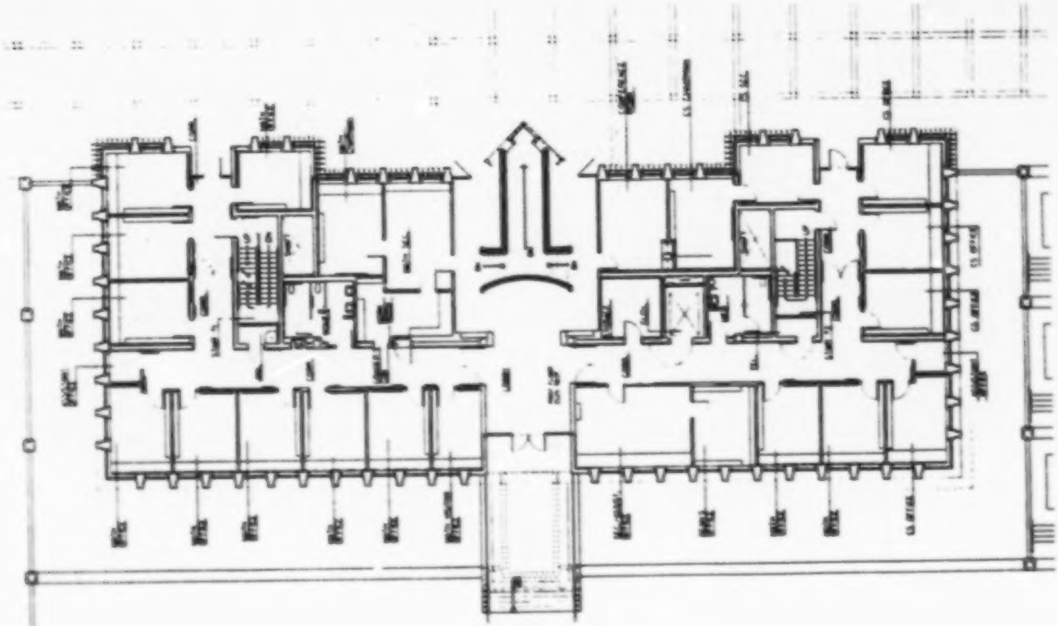
In addition to the labs on the lower floor, a lecture hall and a seminar room are available in another new and adjoining facility (Beckman Hall) which provides an underground link between Olin and the rest of the academic complex. Also located on this level is a prep and storage room, a centrifuge room connected to both the cell and molecular and introductory labs, a walk-in coldroom with both storage and work areas, and chilled seawater and freshwater rooms. All of these rooms provide facilities to support both the laboratory courses and student/faculty research.

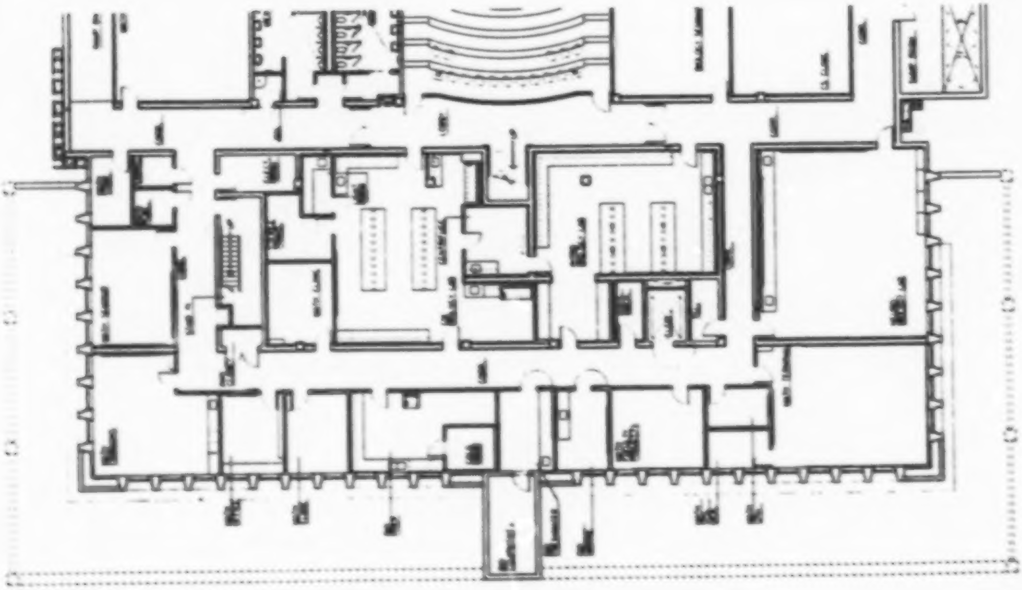
The heart of our biology program is located on the top floor where the faculty offices and student/faculty research labs are located, along with several specialized rooms that support both teaching and research activities. Each individual lab was designed with a particular type of research effort in mind: developmental genetics, population biology, molecular microbiology, physiological ecology, plant physiology, and neurobiology.

The research labs vary in size from 650 to 1,050 square feet, and each adjoins a faculty office. The actual size, shape, and layout varies according to the work the lab is intended to support. The molecular microbiology and developmental genetics labs, for example, are connected, and the total size of this suite is over 2,000 square feet, including the two faculty offices. A total of eight to ten students can conduct research on a full-time basis in the summer in these two labs, sharing a variety of special facilities and equipment.

During the academic year, this lab suite continues to serve as space for senior research (which students may enroll in for up to six credit hours per semester) and provides special facilities for experiments that are being carried out in the formal laboratory courses. Examples of the latter might be HPLC, research-grade microscopy, and fluorescence microscopy. These labs include built-in student desks that promote a sense of student/faculty collegiality, in addition to giving the students a "home" away from their dorm room and a place to study while waiting for their experimental procedures to develop. These labs are also laid out in useful functional areas with both stand-up and sit-down benches for specific research activities, a media/solution preparation area, a glassware storage and dishwashing area, and an instrument area. One of these labs even has a "worm room."

The result is that an outstanding center for molecular biology research is available to HMC undergraduates. This center and the other equally well-designed research labs in our new Olin building support the philosophy of the college to provide the very best hands-on laboratory experience, one which culminates with a significant senior research project.





CHEMISTRY LABORATORY ARRANGEMENT

The Kalamazoo College Story

The Dow Science Center at Kalamazoo College was completed in 1992 to house the departments of biology and chemistry. In planning the new building, the faculty and administration worked very closely with the architect and principal engineer so that the effort was a collaborative one. A critical element in the early phases of planning was a series of visits to recently built science facilities at neighboring colleges and universities. We learned as much about what to avoid as about what to adopt.

In the new facility, the chemistry department occupies two of the building's three floors. On the ground floor, we placed introductory laboratories, the stockroom, other storage spaces, and the office of the director of laboratories. The second floor contains classrooms, departmental offices and upper-level teaching and research laboratories. On the third floor, we arranged the department's spaces in a square, with offices (one for the department, five for regular faculty members, one for a visiting faculty member), student-faculty research labs (384 square foot average; typical capacity three students), and the adjacent chemical synthesis and chemical measurements laboratories (955 square feet each) on the perimeter. Each has exterior windows. In the inner, central part of the square floor plan are the chemistry library, the computer laboratory, five individual instrument laboratories, and a separate sample preparation lab. Most of the inner rooms have a hallway window allowing passersby to observe the activity inside.

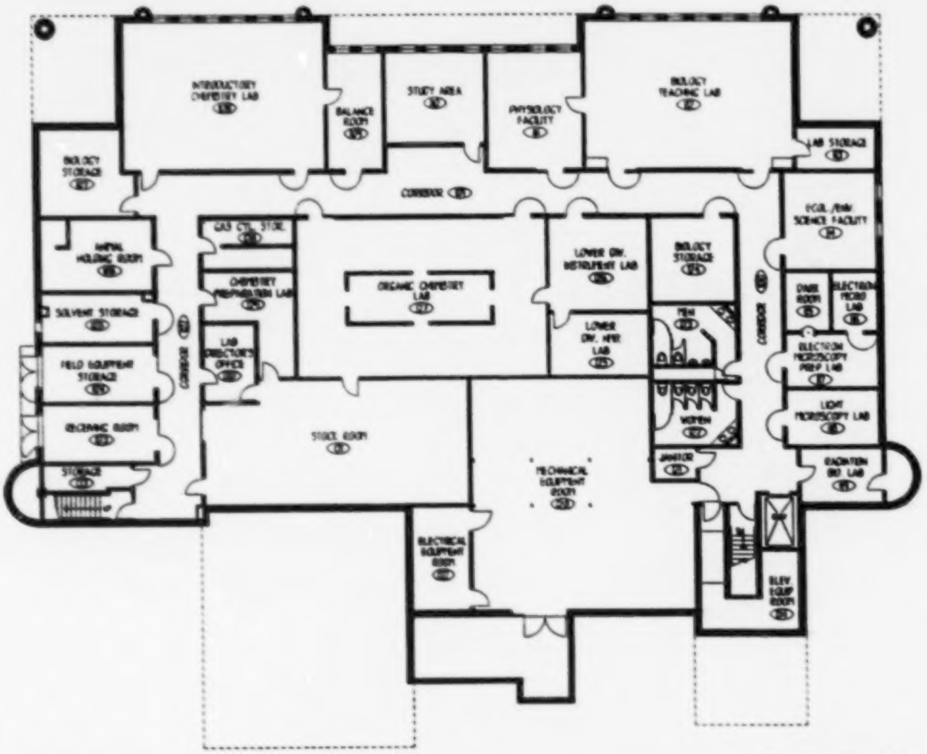
Each faculty member's research lab is located near her or his office and contains some desks for students. These individual research labs, five in all, were designed largely to meet the needs of current faculty members; the chemical synthesis and measurements laboratories were planned for accommodating additional research space needs. This allotment has greatly enhanced our capacity for chemistry research, and we have seen an appreciable increase in the number of students pursuing research in the department.

On the first floor, the introductory chemistry laboratory (1,121 square feet) sits on the perimeter of the square floor plan and has both interior and exterior windows. Adjacent to it is a separate room for analytical balances. The organic chemistry lab (1,495 square feet) was a challenge for us to design in the planning stages. This lab has always seen very high traffic much of the year at Kalamazoo, and we were concerned that it be safe for such a high volume of use. In many of the organic labs we visited, we found that fume hoods are often spread across the rooms in an overpowering way. We wanted a safer and less claustrophobic approach. Fortunately, at St. Mary's College in South Bend, Indiana, we found a model for what we wanted and planned our lab following their design.

Our organic lab has twelve 8-foot working hoods, each with space for two students, arrayed around the perimeter of the room. Locked equipment drawers below these hoods are assigned to each student. One 5-foot hood, with a flammable solvent storage cabinet below and connected to it, serves as a solvent and corrosive reagent dispensing station. A central instrument area, accommodating balances, melting point equipment, and small Gcs, is enclosed by glass walls. From this area, nitrogen cylinder gas can be fed to each of the hoods. Around the outer edge of the instrument island are open working benches with large sinks, and, to conserve floor space, under these are additional equipment drawers, refrigerators, freezers, ovens, and an ice machine. The net effect of the overall lab design is to provide a more open environment so that instructors can continuously observe all students working in the lab.

The central instrument area in the organic lab receives positive air flow from the ventilation system, as well as air movement from the hallway into the lab. Because of the high air flow through the room, it has its own energy recovery unit in the mechanical penthouse while the other labs in the building are served by two large units.

In the three years that the chemistry department has been in the completed building, we have found that this handsome, well-designed, and well-constructed building has exceeded our expectations. It should enable us to build upon our long tradition of excellence in science teaching and research.



DOW SCIENCE CENTER - KALAMAZOO COLLEGE

Clark Atlanta University Center for Science and Technology

Atlanta, Georgia

Architect:	Steven & Wilkinson/ Millkey & Brown Atlanta, Georgia
Lab Designer:	Earl Walls Associates San Diego, CA
Size:	108,000 GSF 130,000 NSF
Research labs	64,155 NSF
Greenhouse & Support facilities	2,000 NSF
Construction Cost:	$21,000,000
Completion Date:	February 1994

View of Research Center for Science and Technology exterior.

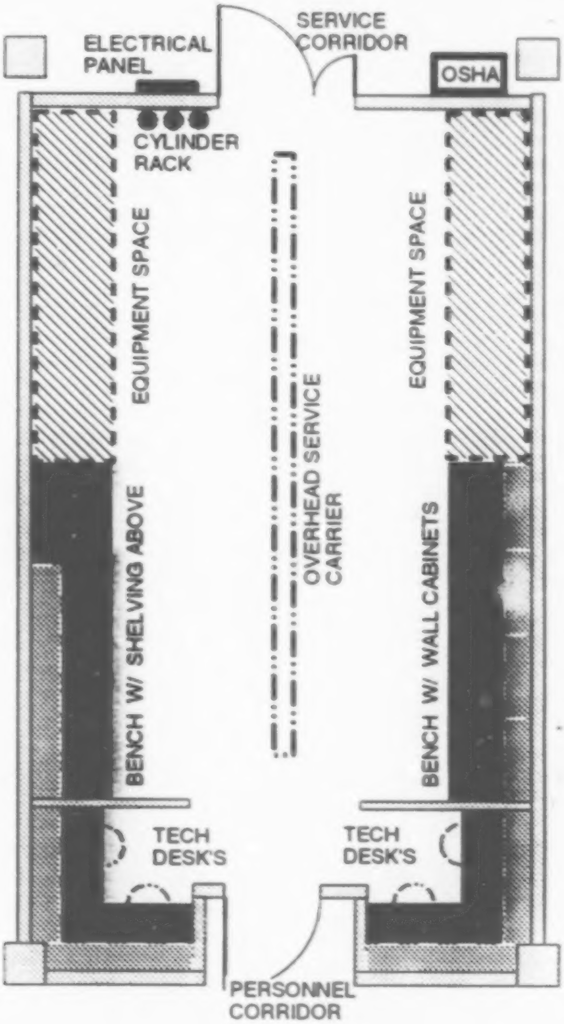
The Research Center for Science and Technology at Clark Atlanta represents a major new interdisciplinary approach to research and teaching. It is organized as four research centers in Basic and Applied Energy Research, Polymer and Materials Research, Biotechnology Research, and Computational Sciences Research. The faculty expertise to support these centers is drawn from the departments of biology, chemistry, mathematics and computer science, and physics. Basic and applied research plays an essential and primary role supporting Clark Atlanta University's overall objective of establishing itself as a center of excellence in scientific and technical areas.

The Center is constructed at the southwest corner of the quadrangle, between and connected to Dean Sage Hall and the biology building. Organized into two architectural elements, the smaller component contains the Center's more public-oriented functions defining the quadrangle. A second, larger element houses all the research and research support activities and has been articulated to break down its visual mass, presenting a more friendly appearance to the rest of the CAU campus and adjoining Morehouse College buildings. The building is clad in brick and trimmed in limestone with windows and openings similar in scale to those surrounding the quadrangle, ensuring a harmonious campus relationship.

Physics laboratories, located in the basement and second floor, are part of the Center for Basic and Applied Energy Research. Laboratory spaces are designed based on a 10'-6" by 38'-0" planning module utilized for both research and teaching spaces. This planning module defines a certain regularity and repetition in the shape, size and arrangement of the programmed spaces and basic utility locations accommodating a diversity of space assignments. This assures that the laboratories can adapt over time to a change of need without requiring major changes to the laboratory systems.

The open laboratories, designed for four to six persons each, provide students with individual bench, equipment, and workstation space around the laboratory perimeter. Overhead service carriers, located in the middle of the laboratory at 8'-0" above the finished floor, carry electrical power and plumbed laboratory services facilitating the changeable arrangement of apparatus and equipment for individual or group research projects.

Laboratories on each floor are organized on a central service corridor concept. This service corridor facilitates the distribution of laboratory mechanical, electrical and plumbing services in a single, accessible zone. Utilizing this design scheme allows laboratory services to be properly integrated into the overall design concept.



Outline.

Interior lab shot.

By creating highly adaptable research and research support spaces. The plan minimizes future costly and time-consuming disruptions to ongoing research and instructional activities for routine maintenance or change of laboratory function. The service corridor can be accessed from a public corridor located at either end or from the laboratories directly.

Formerly disparate research activities were consolidated into the Center, creating one interdisciplinary state-of-the-art science complex, to further promote Clark Atlanta University's comparatively unique role as a teaching and research institution mandated to achieve quality training of minority scholars and professionals. To foster further a sense of interaction, faculty and departmental offices are grouped together in science communities which are intermingled with common activity areas shared by faculty and students alike. These strategically located common facilities (i.e. student study carrels, break areas, conference rooms, shared equipment rooms) create an atmosphere for casual meetings and encourage serendipitous exchanges to occur.

ANIMAL FACILITIES

The Macalester College Story

In June 1995, Macalester College began the expansion and extensive renovation of Olin and Rice Halls of science, overall a $20.4 million project. Both Olin, which houses chemistry, physics, and math/computer science, and Rice, which houses geology, biology, and psychology, buildings had been constructed in the late 1960's with support from the F.W. Olin Foundation. Although modern in their day, neither was configured to accommodate the extensive student/faculty research collaborations and investigative approach to learning that characterize science education on our campus today. Just over half of our current science faculty have been recruited since 1989; all have active research programs involving students. And while we had much of the equipment needed for the work of these faculty and students, from more than twenty-five NSF Instrumentation and Laboratory Improvement grants and grants from a variety of private foundations, the science buildings could no longer meet the ventilation and safety requirements, animal care regulations, accessibility standards and ample laboratory space that such activity necessitates.

In particular, as we began to develop a new program in neuroscience in 1988, the need for modern animal care facilities in the Olin-Rice complex became evident. Whereas previously animals had been used primarily for behavioral studies in psychology and occasional dissections, the recruitment of two new neuroscientists (a neurobiologist with a research program relating to the role of excitatory amino acids in pain transmission by rat spinal cords and a neuropsychologist, whose studies are described below) meant that the variety of species used and the number of animals involved would increase; it also meant that the research procedures employed would be physiological as well as behavioral. In addition to the need for proper facilities for the care of the mammals used by our neuroscientists, a major ecological research project funded by the U.S. Environmental Protection Agency required the accommodation of flow tanks and streams for a variety of mollosks. Finally, the research of another new faculty member, an animal physiologist in the area of melatonin production and the endocrinology and neuroendocrinology of vertebrates and invertebrates, required facilities for housing a variety of reptiles and arthropods.

Our problems to be addressed in the renovation were many, particularly in regard to animal facilities: animal quarters were located in the middle of the psychology department facilities, one floor above and at the opposite end of Rice Hall from the neurobiologist. Although species could be separated, animal rooms did not have the ventilation and temperature control systems, lighting, or security systems currently stipulated by NIH and AAALAC standards. Without a separate animal surgery facility, procedures had to be performed in the teaching lab under fumehoods in order to prevent the escape of anesthesia into the room, a slow process when multiple animals are involved.

As the renovations were planned, a key objective was to have animal facilities that not only met national standards, but ones that were also well positioned to support all the laboratories that might need them, and do so in an arrangement that would maximize efficiency and security. A fortuitous solution to our problems became obvious as we looked at the link that joined Rice and Olin Halls at all three floors. This "connection" contained two facilities no longer useful for the current program: an outdated planetarium and a multistory auditorium used originally for large science lectures but now only for Saturday night movies. The planetarium and auditorium dominated this link between the two buildings; they actually created a barrier to the free flow of traffic and to collaborative activities between the chemistry, physics, and math/computer science departments in Olin Hall and the geology, biology, and psychology departments housed in Rice. Thus, in the first phase of the renovation and expansion project this link was completely demolished, enabling Macalester to build in its place a structure that will create a seamless interface between Rice and Olin Halls.

This new facility, now under construction, will contain a basement service level, first floor animal care facilities, and directly above these, neurobiology, immunology, and animal physiology laboratories on the second floor. Neuropsychology and animal behavior laboratories—as well as organic and biochemistry laboratories—will be on the third floor, and a penthouse will contain HVAC systems for the entire

Olin-Rice complex. Connecting the labs with the animal care facility is a limited-access, card-secured elevator that will enable animals to be carried from the loading dock entrance at the basement level to the animal facilities and from there directly up to the laboratories without any transport through public corridors.

The animal care facility itself occupies 2,152 net square feet of space (exclusive of the elevator) and contains two animal testing labs, two testing and storage labs, three holding labs, a surgical suite, a supply storage room for bedding and dry materials, a cage washer and waste handling room, an aquarium tank room, and the somewhat unusual amenity of a locker room with showers for animal handlers. It also includes an office for the colony manager, a handicap toilet, and connecting corridors. Each room has separate climate and lighting controls and independent ventilation systems to avoid cross contamination of species. All systems are connected to an emergency back-up system in case of power outages. Sick animals can be isolated, as can newly arriving animals until they are tested and declared healthy. Impermeable materials and fixtures, including floor and wall tile and magnetically closed and sealed doors, among others, will provide control against contamination, vermin infestation, and light penetration. Security will be maintained by a limited number of door accesses (only two for the entire animal facility), with identity card admission. All rooms will be finished in materials and fixtures that ensure ease of cleaning.

Each species can be housed separately, with enough holding rooms to accommodate additional species not now used at Macalester or currently not covered by national guidelines. For example, reptiles and invertebrates are not currently addressed in the guidelines and will be housed in environmental chambers adjacent to the animal physiologist's lab on the second floor. Nevertheless, if future guidelines cover these creatures, there will be adequate separate space for them in the animal facility as well. The surgical suite will enable procedures to be conducted in a well lighted and properly equipped and ventilated facility instead of in the teaching and research laboratories above.

The protections ensured by the new facility will be particularly helpful to the work of our neuropsychologist who has a major research grant from the National Institute of Drug Abuse. The focus of his research is to study acute and conditioned hyperalgesia with the hope of suggesting novel approaches for the control of pain and the treatment of addiction, investigations involving central nervous system neurochemistry, behavioral, and neurocircuitry lesion studies. The number of rats required will be more than double the number able to be accommodated in the old facilities. As the faculty member notes, if an animal gets sick or dies, new animals must be obtained, trained, and tested, squandering significant research time and money, over and above the lost animal life. The new facilities will reduce such waste to a minimum and protect the health and safety of the animals, as well as of the humans who handle them.

An important benefit, because of its location, is that the new animal facility will serve as a physical reinforcement of the interdisciplinary collaborations developing among our biology, psychology, and chemistry departments, particularly via the new neuroscience major. By pulling those laboratories that depend on animal use together around the animal transport elevator, the new configuration will make joint projects across disciplines and subdisciplines at Macalester easier and more efficient. Thus, we believe that the demolition of obsolete facilities, and their replacement with a shared animal facility and research laboratories that can be effectively served by it, will help remove both physical and psychological barriers to the cooperation among disciplines that we expect will characterize science and science education for many decades to come.

SHARED SPACES

The Wellesley College Story

Identifying common activities by the building users will give you some critical information as you begin to plan new spaces and add up footage that people think they will need. Try to avoid creating many small spaces for doing things that can be carried out better in a single shared space. The sharing of space is not only economical in terms of square footage, but it can also be conducive to creative thinking by bringing people together out of their disciplinary or departmental niches. Shared spaces are also an efficient use of personnel, of time, and of budget. The very act of entertaining ideas of hypothetical space-sharing itself often generates productive plans, particularly if the discussions start from a *what if* scenario rather than an *only if* declaration.

At Wellesley, we had the challenge and advantage of creating a science center which was (at least initially) to house seven academic science departments, a common science library, animal quarters, an office for pre-med advising, and the academic mainframe computer. It was to be located adjacent to the existing greenhouses and near the existing astronomy observatory. After almost two years of discussion, we developed final plans for a center that made use of both existing spaces and newly constructed space and accommodated the curricular changes we anticipated—without losing departmental identities. This was accomplished, in part, through goodwill and the eagerness of faculty to work together across departmental lines. It also took some painful discussions about how the innovations we truly cared about could be accomplished if we were willing to share—space, access to support personnel, and instrumentation.

Shared spaces were fundamental to solving our overall space needs. We needed new space, and we had to use space in an existing biology building that was unsuitable for upgrading to meet the HVAC needs of any of the natural sciences. We turned that building into spaces for offices, classrooms, a large common lounge, and the mail room (a very important decision); we put teaching and research laboratories, centralized computer labs, and the science library in the new space.

This seemed undesirable at first, but it has worked well. The flow of traffic from office to classroom, to the lounge, to the common mail room, to the lab has forced people to meet. Conversations with colleagues from other departments are easy and often allow one to ask colleagues questions that really allow interdisciplinary thinking. Biologists rarely talked to physicists before because they almost never encountered one another. Now, one of our most enthusiastic scientists is a physicist who is constantly reminding colleagues, after a spontaneous and stimulating chance discussion: *"Isn't that great. This is what science is all about. Sharing ideas with other scientists who don't see everything exactly the same way you do. This center makes it possible."*

Our center was planned from the beginning to have shared interactive spaces such as a large lounge for everyone in the entire complex—staff, students, and faculty from all departments. This is a place to gather, to meet students, for students to study, to eat lunch, and to just relax. During exam time, this is one of the areas on campus that is open all night for students who want access to computers or to study together. It is popular with students from all disciplines. Some departments also have seminar rooms that are designated as lounges or common rooms when they are not being used for teaching or departmental meetings. We, however, did not plan departmental meeting rooms into our building. Teaching and research labs were more important.

We also planned a centralized area for offices for departmental chairs and departmental secretaries (near the lounge and the mail room). Thus, during heavy advising periods, students can readily plan their schedules and get signatures in one location and get answers in speedy fashion.

A fundamental goal was to provide shared spaces in the form of a common stockroom, shop facilities, animal quarters, hazardous waste storage, and a single office from which supply purchase orders would be made. (Each department still maintains its own budget and draws on it when ordering.) Since the stockroom manager is most knowledgeable about our inventory of hazardous chemicals, he is also the person responsible for safety and storage of hazardous waste, including radioactive waste. The tool shops and woodworking shops work somewhat the same way. They are located together in the basement adjacent to the shop.

Common animal facilities for biology, biochemistry, and psychology seemed the most feasible way to provide facilities that met government regulations. They are located in an area adjacent to biology but accessible to anyone who needs the facility. Costs are defrayed by the science center, but departments are expected to contribute to the purchase of food and litter. Since biology had animal facilities before the science center was formed, the need for attendants was met by current staff.

Most instrumentation in the center, other than very special research equipment, is located in common instrumentation rooms to be used by any qualified and authorized user, student or faculty. A single laser lab is housed near both chemistry and physics and serves the needs of those departments. Biochemistry, genetics, cell biology, and microbiology, and all of the teaching labs share an instrumentation lab which is located near all of these spaces. Students and researchers go to this location to use refrigerated centrifuges, ultracentrifuge, spectrophotometers, and gas chromatographic equipment.

The desirability of isolating molecular biology experiments from the regular traffic flow has resulted in one set of equipment being placed in that laboratory. This instrumentation is, however, available to others who come there to use it.

Having centralized instrumentation labs also relieves the pressure on floor space in teaching and research labs, where we store small pieces of instrumentation in cabinets for ready access. It also means that individual laboratories are not permanently dedicated to the teaching of a single field; they can be used in different semesters for different subjects.

The layout of our labs and support areas for them is such that teaching laboratories open out into a common support space. For chemistry, this means that all of the balances, instruments of spectral analysis, gas chromatographs, etc., are equally available to students in every lab. This makes instruction in usage easier and also reduces the number of instruments required. This in turn has saved money for the purchase of some highly specialized equipment, such as the NMR. It is in this zone of the layout that one also finds small rooms devoted to specialized activities: cold rooms, temperature-regulated incubators, an inoculating room, a tissue culture room, and anatomy storage of specimens and models. These areas are available to all also.

The academic computing center in the new spaces also is open to the entire campus community on a 24 hours-a-day basis. Access after 11 P.M. is regulated by campus police. A variety of computers are located here, some of which are unique to that space. This is also where the computers programmed for use by students in the computer science department are housed.

We have operated traditionally on the basis that classrooms and lecture halls are held in common, unless they have been generated and equipped for a specialized purpose. Even then, when they are not actually in use, they are often available for use by students and faculty knowledgeable in the use of the equipment housed therein. This concept makes it possible to plan an adequate number of classrooms without having each department with rooms vacant several hours of the day. To assure appropriate classroom usage, the college requires that all departments offer some courses at each of the available hours so that students and classroom demand are distributed.

Sharing and openness was a formative concept for our building. To that end, we fundamentally have an open construction plan with very few walls and barriers to vision. The great advantage to the open plan is that you can see and be a part of everything. The view is wide and you feel free and unconstrained in our building. Light is abundant and the colors are bright and cheerful. Open space is inviting for sitting in small groups or for isolated study at the end of a corridor. Common space is truly user-friendly. Our students feel they belong; this is their science center. They like being here, and they show it off to their friends with great pride.

Wellesley College 1991 Expansion to the Science Center

Wellesley, Massachusetts

Architect: Perry • Dean • Rogers & Partners

Size: 41,000 Square Feet

Phase I: Renovate 30,000 Gross Square Feet

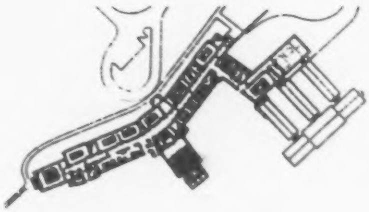
Construction Cost: $8,900,000 (1991 Expansion)

Completion Date: October 1991

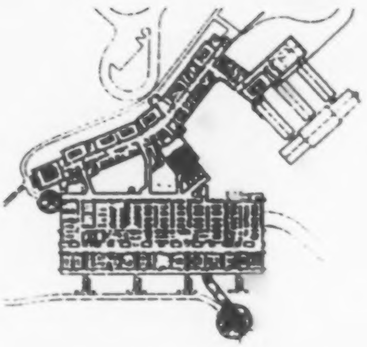
Dramatic growth in student enrollment and rapid changes in science technology impelled Wellesley College to study the prospect of expanding the Science Center. The original center, built in 1977, united all the science disciplines in one complex promoting the cross-pollination of ideas and allowing each science discipline to utilize common facilities such as the Science Library, lecture halls, classrooms and special equipment.

The introduction of new technologies both in the field of pure science and in science education had the greatest impact on the actual form of the 1991 expansion to the Science Center.

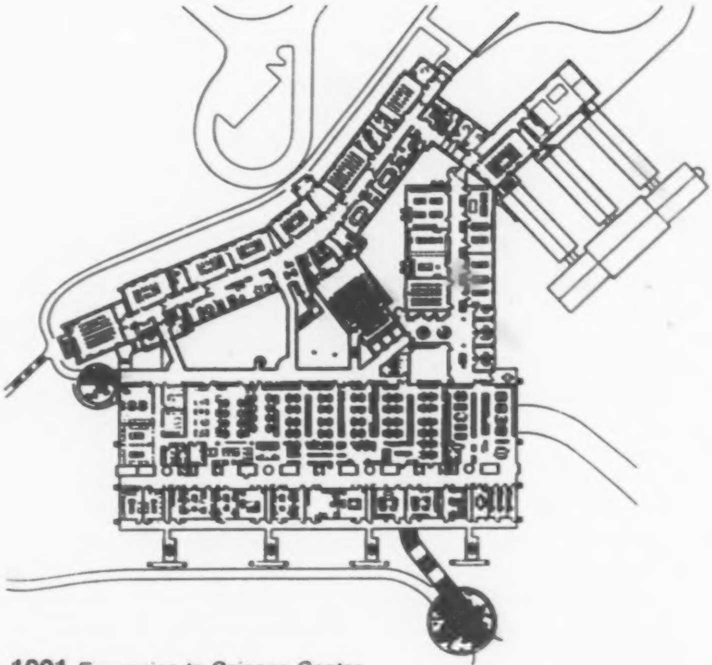
The importance of the computer to both the sciences and the greater Wellesley College community meant designing spaces which are easily accessible to all. The open and inviting character of the 1977 FOCUS set a strong precedent for continuing the concept in the primary public spaces, which in the 1991 program were academic computing and computer science studies. The canopies were designed to address natural light entering the MINI-FOCUS through clerestory windows. The computer stations are connected to the college's main computer network which makes the facility useful for all. Also, a resource station has been designed to assist computer users with specific problems arising on their computers.



1923 *Sage Hall*



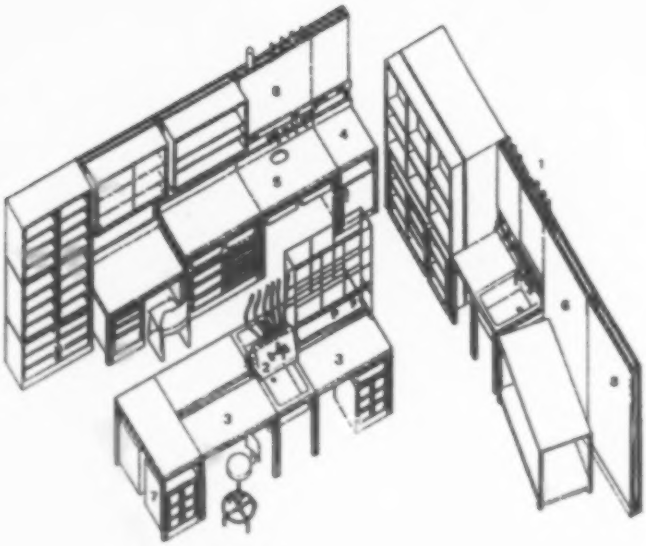
1977 *Addition to Sage Hall*



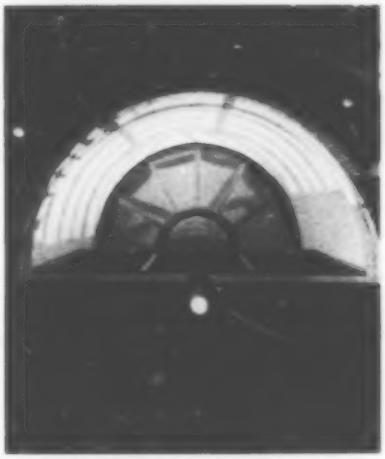
1991 *Expansion to Science Center*

The 1991 expansion differs from the 1977 addition in its treatment of controlled lighting and individual labs and classrooms. Laser physics requires total darkness, much like a photographic darkroom. Computer science seminar rooms call for dimmable direct light on students' terminals while also directing bright beams of light on various portions of the markerboards. Molecular biology requires an adjacent darkroom, a tissue culture room and a chamber to treat radioactive material. These specific requirements are characteristic of modern sciences not common in 1977.

The introduction of new technologies both in the field of pure science and in science education had the greatest impact on the actual form.



Flexible Casework Diagram
1. *Overhead plumbing service*
2. *Fiberglass service module*
3. *4' x 2' table*
4. *2' x 2' table*
5. *4' x 2' table with cup sink*
6. *Chalkboard on stanchions used as room divider*
7. *Undercounter storage unit containing tote trays*
8. *Tackboard*



A view looking up at the skylight above the circular stairs. Utility pipes are brightly painted.

Typical teaching classroom workstation in the 1977 and 1991 Science Center addition.

The 1991 expansion included a computer center for students use.

Despite the technological changes within the laboratory, many elements of the 1977 addition were carried over to the 1991 expansion. Foremost of these is the use of the flexible lab casework developed to allow faculty to rearrange the laboratories. This casework allows for quick disconnects of services and the adjustment of counter height and lengths.

The Wellesley Science Center has evolved into a facility with a broad spectrum of spaces and functions. The 1923 Sage building provided traditional offices and classrooms, the 1977 addition featured vast open public spaces and flexible laboratories. The 1991 expansion achieves a synthesis of the best features of both its predecessors: a combination of private offices, controlled classrooms and open public spaces. Several schemes were analyzed to determine the most workable location for the 1991 addition.

Many elements of the 1977 addition were carried over to the 1991 expansion. Foremost of these is the use of the flexible lab casework developed to allow faculty to rearrange the laboratories.

The result of that analysis proved the continuation of the focus concept allowed for excellent adjacencies of program science spaces and convenient circulation patterns throughout the Science Center.

Office Spaces. There are different kinds of offices within an academic building used for teaching and research in the sciences: those used by faculty members, those used by technicians and secretarial support staff, and those used by students. The size and location of offices has an impact on air and light quality, two environmental issues which are critical to productivity. Having offices located so they have windows can be important, particularly those used for many hours during a day. As mentioned earlier, care must be taken to avoid heat gain and glare from natural and artificial light, but creativity (and concentration) can be enhanced by feeling connected to the outside world.

Faculty offices can range from as small as 100 NASF to as large as 180 NASF, depending on standards set by the institution or perhaps by a state regulatory agency. Space standards most commonly are in the range of 110 to 140 square feet, although such standards often represent a range rather than a precise figure.

How faculty will use the office—as a place for regular face-to-face consultations with students, as a place for personal research and reflection, or as a place from which electronic discussions take place with colleagues around the world, or all of the above—determines its design. Faculty are both scholars and teachers, and their office spaces need to accommodate both roles. Offices need to be visually and acoustically private yet provide space for work related to classes, seminars, and student advising.

Faculty offices can either be located adjacent to other offices (e.g.: centralized) or located adjacent to teaching and research spaces (e.g.: decentralized) distributed throughout the science building. Offices adjacent to other offices have the advantage of increasing the potential for interaction with office occupants. Offices located adjacent to research and teaching facilities have the advantage of increasing the potential for interaction among a variety of science facility users (e.g.: students and faculty). Centralized offices can effect energy conservation by facilitating recirculated air via a dedicated air handling system.

As electronic communications—, between classroom and office and lab, between students in dorms and faculty, and between researchers in different parts of the world—become used more commonly, offices may look different than they do today, with fewer books and archival materials but with the addition of high-definition monitor screens for two-page comparison and collaborative work with students in different classes, and other electronic and teleconferencing equipment. Although it is never clear precisely what will be needed in the future, the building infrastructure should accommodate the possibility that all faculty offices, at some point in the life of the building, will need to have easy access to internal and external teleconferencing and electronic networks. Providing spaces for adjunct faculty (which can be two-person offices), and for visiting and/or emeriti faculty is another way to anticipate needs of the future.

Office space for support staff usually ranges from 90 NASF per person in a shared office to 120-140 NASF per person in an individual office. Additional space should be provided for waiting, files, and for workrooms. A centralized space for all support staff, serving all departments and programs, is an approach that works in some institutional settings and allows for sharing of office equipment.

Offices for upper-level students and/or graduate students, which can be shared by up to six students, usually range from 40-60 NASF per student.

In the floor plans presented throughout this Handbook, different approaches are suggested to sizing, locating, and designing offices for faculty and staff, approaches that reflect specific institutional goals, as defined in the programming process.

Conclusion. Since 1992, Project Kaleidoscope has sponsored eight workshops and colloquia on undergraduate facilities for science and mathematics, in which over one hundred and fifty institutional teams have participated. Based on the experience of these meetings and the experience of institutional teams whose planning has been informed by these meetings, we suggest facilities that work are those that:

- clearly reflect the educational goals for the sciences and mathematics within an overall institutional framework, for the immediate and the long-term
- support learning that is experiential, hands-on
- recognize the increasingly social character of scientific research and teaching by facilitating productive interaction between and among students and faculty
- acknowledge the role of serendipity in the doing of science, by including spaces for exploiting the unplanned, teachable moment
- are so inviting, safe, and well equipped that they are used by students and faculty most hours of the day, seven days a week
- anticipate the future by providing flexibility in space and infrastructure
- respect and reflect the community that brought them into being
- contribute to the humanity of the campus.

PART FOUR

WAYS AND MEANS

Chapter VIII
The Project Budget

Chapter IX
Operating Budgets

Chapter X
Fund-raising

Because of the high cost of building, equipping, and maintaining science facilities, the specter of *ways and means*—fund-raising, budgeting, and financing—will always be present in your discussions, and those are the issues to be discussed now. However, planning for the renovation or construction of science facilities is a complex process requiring the involvement of financial officers and development officers from the very beginning. Their charge is to ensure that the project is planned so it makes financial sense for the institution.

The final decision about when and how to move ahead on the project will be made by the executive committee based on a careful analysis of your priorities, confirming that this project is a timely opportunity to achieve distinction in an area central to the mission of your institution. Following upon that decision, parameters for the project budget will be set, fund-raising capabilities explored, and the potential impact on current and capital budgets determined.

The best plans to renovate an existing structure or build a new facility remain only plans until you have funds in-hand or pledged to meet project costs. Fund-raising, use of internal resources from current and capital budgets, and debt financing, are means to assemble the funds necessary to move ahead on the project. Decisions made in each and all of these areas will have a ripple-effect through your institution; timing will become a critical factor in your financial considerations.

The project must be the right one for this time for the constituency from whom you seek grants and gifts. It must be an appropriate and timely use of internal funds (allocated or reallocated) or to expand or restructure long-term debt, and it must fit into your long-term institutional priorities for renewing program and plant. As financial and development officers have been working with other campus leaders throughout the long process of planning your new spaces and structures, they will be able to make decisions about the ways and means of the project to keep your planning focused and on track.

CHAPTER VIII: THE PROJECT BUDGET

Introduction.

We address here the relationship of budget to program, the factors that contribute to an effective budget, and the difference between the *budget* and the *tools and processes* used to keep project cost within budget. The project budget must be sensible, arrived at in a rational manner by members of the project committees and their agents and consultants (bond counsel, architects, construction managers, and others). The project budget must support the facility program as it has been defined in the predesign process, including the desired level of building quality.

Most important for the project to proceed and to succeed, the budget must be within the reasonable capacity of your institution—from the fund-raising perspective and from the perspective of operating and capital budgets over the long-term. Too high a budget will kill a project early-on; too low a budget will kill it later.

The project budget is an important document from both the construction and the development perspective. It illustrates, to prospective donors and to the campus community, the care with which you have proceeded in planning, and how this single project fits into institutional planning and priorities.

In the predesign stages, you addressed issues in regard to strategic and operational planning, considered the campus master plan, and defined the program for the new spaces and structures. In doing so, you articulated how this project links to broader institutional priorities, and outlined parameters for quantity and quality of space, plans for existing facilities, and the hoped-for time frame for the project. With this information and material well in-hand, and with a clear sense of appropriate cost histories for the institution and your geographic region, a manageable budget can usually be established before the formal design development process begins.

It is, however, impossible to set the budget for some projects prior to design. For projects with unknown funding limitations, those with program elements that require design development before final decisions can be made, and those that require master planning to determine phasing, possible use of existing facilities, or site development, you must wait and develop a final budget at a later time in the process.

The Project Budget.

The final project budget will include, in addition to construction costs, other costs directly and indirectly related to the project. The budget may include line items as diverse as endowments for equipment or short-term interest expense. What to include depends on the institution's circumstances and how the project budget will be used, for example, whether it is important for fund-raising. The following discussion of some line items may be helpful in determining the comprehensiveness of your project budget. In developing the project budget, think about whether or not to include:

◆ **equipment.** The selection of laboratory, computer and audio-visual equipment can play an important role in the success of the facility and the flexibility with which it can be used. Designers must anticipate wiring for local area networks, linkages to other campus computer facilities, compatibility of computer and A/V software, and ongoing budget needs for maintaining software currency and later upgrades of hardware.

◆ **furnishings.** Furnishings must be planned not only for labs, offices, lecture rooms, and community spaces, but also for space dedicated to "community" use. Often, the comfortable arrangement of casual seating can be influential in creating areas for the informal communication within a learning community, and thus can be a significant factor in developing the kind of community of learners to which you aspire.

Depending on budget parameters, you may decide not to include any computers, office furniture, or instruments, reusing what is available, in order to stay within budget. Such items can be added incrementally when funds become available, while a lab cannot.

◆ **fees for architectural, engineering, and consultant services.** Realistic budgets for these functions must be developed, maintained, and updated with project progress.

◆ **institutional contingencies.** In addition to contingency amounts budgeted by contractor, institutions are wise to budget for additional contingencies to address cost increases that surface late in the project.

BUDGET CONSIDERATIONS

The Chief Financial Officer's Perspective

Institutional teams have a challenging task to ensure that the development and design of the facility is compatible with the project budget (and the resources available), so that drastic redesign and/or the need to secure additional project funding can be avoided. It is extremely important that everyone on project committees knows and understands, at the earliest time possible, exactly how much is available to spend. Ideally, budget parameters should be known before the schematic and design development stages begin.

Establishing the budget, particularly the construction budget, is a delicate balancing act, one that requires attention both to the facility program that has been defined and the resources available. In nearly every situation the cost of the program that has been defined exceeds available resources; this is the law of construction. It is therefore critical that the very first budget estimates be comprehensive, and include all project costs—not just direct construction costs.

From a practical standpoint, the project budget is under review by the project team throughout the entire project. There are, however, several points that are particularly critical: at the end of the schematic design phase; at the end of the design development phase; at the point when 50-70 percent of the construction documents are complete; and when the construction documents have been sent out to secure bids from the contractor and subcontractors. If the project is out of budget-balance at any of these points, it is necessary to take action before proceeding to the next phase.

There will always be pressure to increase the cost of the project, from the time of the first thoughts of possible new spaces right up to the final point when the facility is turned over to the institution. If the budget is to be maintained, the project team must have in place a process (agreed to by all) for reviewing issues that arise and for making decisions about budgets in a timely manner. The outside members of the project team (architects, planners, contractors, etc.) bring experience and expertise to the effort, and are very helpful as difficult decisions are being made (another reason why it is extremely important to select the right architects, consultants, and contractors!).

In developing and monitoring the budget, be certain to pay attention to change orders. While some may be avoided, there are reasons that change orders will be required, including:

- changes required by regulatory agencies during field inspections/reviews
- building features not known or shown on existing documentation that surface during demolition and/or construction (especially with renovations)
- field or site conditions (especially underground utilities) that were different than originally anticipated and budgeted for
- problems with delivery of materials not in accordance with the schedule
- changes to the facility program and an increase/decrease in the scope of the project
- errors or omissions in the definition of the facility program and/or design
- additional resources becoming available that permit the project to expand.

The key to avoiding change orders is taking time on developing and reviewing design documents at each stage of the process. Change orders will be needed; however, they should proceed through the same review, cost-determination, and approval process by which other budget line items have been determined.

Finally, it is vital that there be a very good accounting/record keeping system for the project. You must be able to track the budget, encumbrances, expenditures and change orders in a timely and accurate manner. The project team and the executive community must know where the project budget stands at any point during the project.

Project Budget.

The following chart of accounts identifies many possible budget line items to be included in a total project budget. Although proportions vary from project to project, non-building costs can be 25 percent or more of the total project budget.

I. PROFESSIONAL CONSULTANT COSTS

- Land and building appraisals and surveys
- Soils investigation
- Hazardous material surveying
- Environmental impact statement
- Historic preservation
- Consultant fees
  - Programming/master planning
  - Cost/construction management
  - Architectural
  - Structural
  - Civil
  - Mechanical
  - Electrical
  - Acoustical
  - Laboratory planning
  - Landscaping
  - Interiors
  - Signage/circulation
  - Other specialized consultants
- Special inspection (engineering/soils/materials)
- Consultant reimbursables

II. BASIC CONSTRUCTION

- Site work
  - Clearing and demolition
  - Site utilities
  - Access roads and walks
  - Grading
  - Site restoration after construction
  - Landscaping
- Basic construction by building systems
- Overhead and profit
- Temporary utilities and facilities during construction
- Security during construction
- Construction management
- Building permits and insurance

III. OCCUPANCY

- Fixtures, furnishings, and equipment by area
  - academic and administrative offices
  - classrooms and seminar rooms
  - laboratories (teaching and research)
  - common spaces
  - stockrooms and special spaces
  - laboratory instrumentation
  - computer and information technologies
  - miscellaneous furnishings/cabinetry throughout
- Telephone, computer and other electronic needs
- Special fire/life safety treatment
- Special acoustical treatment
- Signage and directories
- Occupancy permit
- Artwork
- Relocation, temporary and final
- Open house/dedication

IV. FINANCE

- Interim funding/carrying costs
- Special fund-raising/development costs
  - Consultants
  - Organization
  - Materials
- Construction and other project contingencies
- Endowment for maintenance and operations

V. ADMINISTRATION

- Internal staff costs
- Advertising
- Printing
- Legal

- **fund-raising expense.** While fund-raising costs are often provided from development office budgets established for that purpose, their inclusion in an overview of capital costs is appropriate, even if the revenue is shown as arising from internal (or unrestricted) sources. Beyond salaries and direct expenses, the fund-raising costs may include consultants, special events for solicitation or recognition of donors, volunteer travel expenses, recognition plaques, and related items.
- **short-term interest expense (up to five years).** It is generally acknowledged that any facility project funded with gifts and grants will encounter an early stage where some heavy commitments to spend are incurred before payment has been made on pledges. Once general contracts have been signed, often the outflow of cash will require more than cash available, thus the use of short-term financing, either from internal or external sources, is necessary.

Furthermore, most capital campaigns accept pledges payable up to five years into the future, and the shortfall in cash from that alone requires an intermediate, temporary funding source. The interest expense payable for short-term financing is a genuine cost and can be substantial in size if pledges are numerous and large in overall size. The amount needed can be anticipated and planned only when the project timetable is firm and when a reliable project cash-flow table can be drawn up. The net cost for short-term financing is the difference between the interest earned on funds held during the early stage of the project and the actual outlays needed during the construction period and the more extended period while the institution awaits payment of all pledges.

Successful projects are created by effective cost management applied consistently from the scope and budget development to commissioning of the building. Effective cost management includes the entire building life cycle. The initial capital invested may only be a fraction of the total cost of a building over its useful life but the decisions made at the design and construction stages can have significant impact on operating costs.

Predesign and Cost Management.

The budget is a target established early in the process of developing your project. *Exhibit 1* illustrates how you can achieve cost savings by making decisions in the early stages, as well as the cost that delayed decisions or changes may have.

Effective Budget Development.

In the process of developing a budget that works, you must:

- manage expectations and acknowledge, by establishing contingencies in cost planning, that change is inevitable
- establish a solid base of needs in a carefully defined, prioritized, and documented facility program
- study as many feasible site and building alternatives as possible within the context of a campus master plan
- establish a well-defined schedule for the project, one that can be easily managed
- make sure the budget has been accepted by all members of the project team
- establish clear responsibilities among the owner, users (project shepherd/project manager), and designers for adhering to a budget that is consistent with and supportive of the facility program as defined
- focus on the process, from beginning to end, as a team effort.

The most important factor in developing a budget that works is that all project team members are speaking, and understand, a common cost language. Failure in budget development and cost management is often a failure in communication rather than a failure in application. Some critical terms and definitions:

Life Cycle v. Nonbuilding Cost v. Building Cost. *Exhibit 2* points out the difference between life cycle costs, building costs, and nonbuilding costs. Other terms for the relationship of building/nonbuilding costs include: construction/project; construction/nonconstruction; and hard/soft costs. (Note that a budget provided by a professional may be only for construction costs, not from the total project budget.)

Estimating. Once you have arrived at a manageable budget, cost estimates become a means of gauging adherence to budget limits, not of adjusting the limits. Estimates at predesign and design phases are shown on *Exhibit 3* as a dashed line. The budget in each example remains constant. Estimates are provided by cost consultants, construction managers, contractors or design consultants.

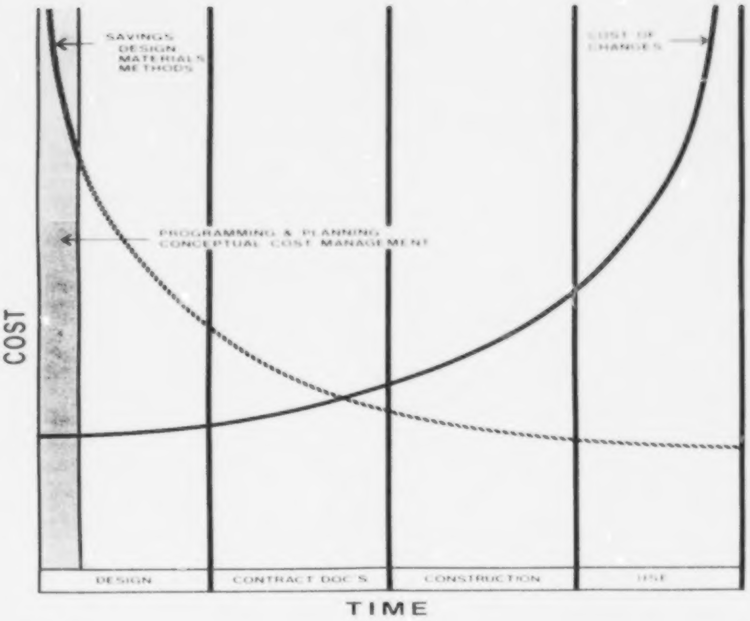


Exhibit 1

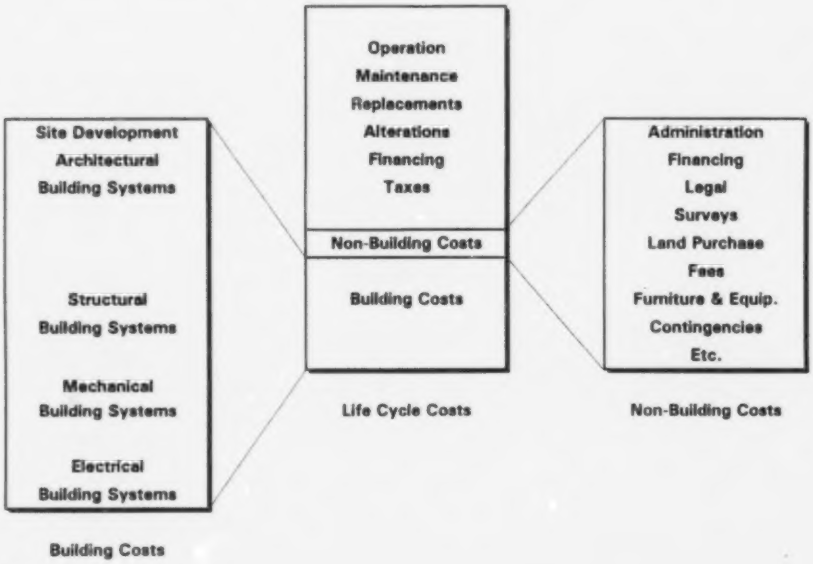


Exhibit 2

There are different types of estimates, including:

- **order of magnitude (ballpark) estimates.** These are based on planning/programming criteria; measurement of occupancy content or gross floor areas, and priced with unit or square foot costs based on historical data. *Expected level of accuracy in a range of ± 20-30 percent.*
- **cost plan estimates.** These are based on planning/programming criteria; measurement of shell/functional areas or the development of cost models, and priced with unit or square foot costs, based on historical data in building systems format. *Expected level of accuracy in a range of ± 15-20 percent.*
- **preliminary estimates.** These are based on conceptual designs (measurement by systems quantity takeoff, and priced with current unit costs in building systems format). *Expected level of accuracy in a range of ± 10-15 percent.*
- **interim detailed estimates.** These are based on schematic design documents (at 95-100 percent completion), design development (at 95-100 percent completion) or contract documents (at 50-75 percent completion); measurement by quantity takeoff and priced with current unit costs in building systems or itemized labor/materials format. *Expected level of accuracy in a range of ± 5-10 percent.*
- **final detailed estimates.** These are based on contract documents at 95-100 percent completion; measurement by detailed quantity takeoff and priced with current unit costs in itemized labor/materials format. *Expected level of accuracy in a range of ± 2 ½-5 percent.*

(Building "systems" refer to construction assemblies such as exterior walls, floors, etc.)

Net-to-Gross Ratios.

Building programs typically are developed on the basis of net space requirements. The total gross square footage can then be estimated by dividing the program net square footage by an appropriate net to gross factor. Some definitions:

◆ **gross area.** The gross area is the sum of the areas of all building floors including basements, mezzanines, intermediate floored tiers and penthouses of headroom height. It is measured from the exterior faces of exterior walls or from the centerline of walls separating abutting buildings. Covered walkways, paved open roofed areas, porches and similar spaces have the floor area multiplied by a factor of 0.50. The gross area does not include pipe trenches, exterior terraces or steps, chimneys, roof overhangs, etc.

◆ **net area.** The net area or assignable area is that portion of the gross area which is available for assignment to an occupant. The net area is measured from the predominant inside finish of permanent outer walls to the assigned room side of corridors or permanent partitions and from the center line of adjacent assigned spaces. For interior spaces surrounded by corridors, the measurement is from the inside face of enclosing walls. The floor area of columns and projections necessary to the building partitions subdividing space are included in the net area.

◆ **cost/GSF.** The cost per gross square foot is derived by dividing the building construction costs by the gross building area.

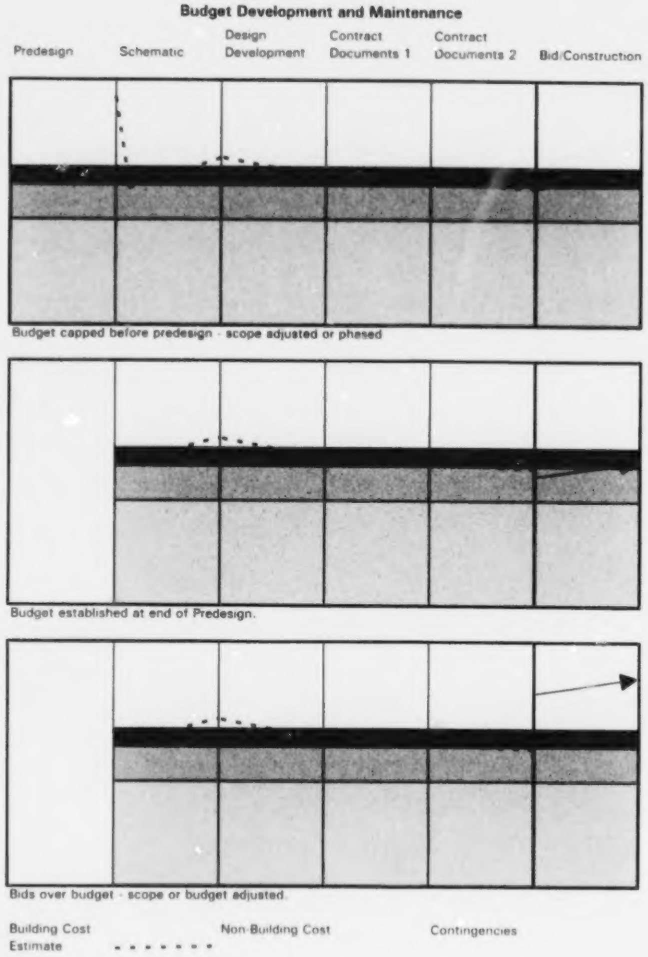


Exhibit 3

You will note by reviewing the many architectural case studies presented throughout the Handbook how the cost/GSF can vary from project to project, geographic region to geographic region. The chart below gives further examples of how budgets (net to gross relationships) are project-specific.

Working closely with your project manager, contractor, architect, and lab designer, you will be able to develop a set of options for the relationship of laboratory and laboratory support area, mechanical and electrical gross area, and lab furnishings to consider as you develop the budget and manage the cost of your facility project.

Several circumstances can reduce the efficiency ratio of a science facility, including:

- **intensity of building systems.** More fume hoods will require more space for mechanical equipment and shafts.
- **building layout.** Different combinations of functional elements will result in varying amounts of corridor space.
- **stand-alone systems vs. campus control plans.** Science facilities that can tap into central campus utilities such as steam, hot water, etc., will require less mechanical equipment space within the building, although the cost of accessing such services must be considered.
- **campus context/site constraints.** Campus context or site area constraints may dictate a certain number of floors for the science building. Multistory buildings, with a relatively small floor plate, have a comparatively lower percentage of floor space dedicated to stairs, elevators, toilets, lobbies, and mechanical shafts than do single or multistory buildings that have larger floor plates.

Special Considerations.

Circumstances unique to your situation may dictate special considerations. You must consider ease and cost of maintenance and alterations over the life of the building, remembering that the most economical building is not necessarily one that has the lowest initial cost. Careful attention to the selection of the construction delivery method will also have an impact on the process of budget development and cost management, as will the establishment of contingencies at each stage of the process. How the building will be used, and the costs of the different elements and functions of the building (including energy conservation and consumption) and making the building accessible to all potential users, must also be considered as you develop your project budget.

Cost Differences. The range of construction costs for science buildings that include a mix of wet and dry labs is in the general area of between $140 and $250 per gross square foot. Differences in costs are due to many factors, including:

- local cost variations (including for seismic requirements)

Net-to-Gross Ratios for 15 Projects

	Gross	Net	Net/ Gross	Laboratory & Support	Laboratory & Support/ Gross	Support	Support/ Laboratory & Support	Mechanical & Electrical	Mechanical & Electrical/ Gross
1.	24,800	16,700	0.67	11,600	0.47	3,900	0.34	1,809	0.07
2.	171,000	103,400	0.60	87,500	0.51	25,300	0.29	19,900	0.12
3.	88,000	50,819	0.58	39,157	0.44	12,731	0.33	6,277	0.07
4.	194,000	119,000	0.61	25,900	0.13	6,000	0.23	18,000	0.09
5.	83,125	54,900	0.66	41,700	0.50	14,300	0.34	12,460	0.15
6.	341,055	212,289	0.62	56,359	0.17	19,217	0.34	62,906	0.18
7.	154,300	96,500	0.63	66,700	0.43	24,400	0.37	16,300	0.11
8.	109,500	66,550	0.61	33,950	0.31	10,450	0.31	10,660	0.10
9.	188,000	117,000	0.62	90,800	0.48	51,500	0.57	31,100	0.16
10.	81,400	45,300	0.56	35,700	0.44	11,700	0.33	9,348	0.12
11.	111,800	64,9000	0.58	51,500	0.46	20,000	0.39	11,220	0.10
12.	73,284	57,000	0.76	17,158	0.23	4,800	0.28	8,500	0.12
13.	122,324	74,125	0.61	66,640	0.54	19,610	0.29	9,600	0.08
14.	175,000	103,000	0.59	61,000	0.35	14,000	0.30	22,000	0.13
15.	81,193	45,552	0.56	29,300	0.39	5,400	0.18	11,531	0.14

- how much HVAC capacity is provided for future flexibility
- the extent of the piped utilities and electrical services and the specialized rooms/equipment (constant temperature rooms, darkrooms, animal facilities, fume hoods) required by the program
- where the mechanical systems are located (rooftop or basement)
- the use of energy conservation measures to reduce lifetime costs
- the amount of space required for service runs in ceiling and shafts
- the fraction of space which is labs, and the relative mechanical complexity of the spaces, and the quality of finishes used
- the amount of casework, its adaptiveness, and material selected.

There are many ways to reduce construction costs that require conscientious consideration from the beginning of the project. For example, if faculty accept an open-lab interior, without extensive "turf-war" discussions, cost-savings may be realized. Open-lab layouts provide opportunities for increased communication between students and faculty; they are more adaptable over the life of the building. The location and number of offices also affects construction costs; although office space is less expensive per square foot than lab space, the necessity (or desire) to provide daylight for most offices may require a complex building configuration, and drive up costs as a result.

Finally, one means to anticipate cost savings over the life of the building may be to consider interstitial space (accessible space between floors for mechanical, plumbing and electrical services distribution). The value of such space is well established, but often the added initial cost makes it an unattractive option, especially for smaller institutions. Interstitial space generates increased design fees, the cost of the walk-on deck, an added three or four feet of exterior wall height, stairways and elevator shafts, longer structural columns, and vertical electrical, HVAC, and piped service runs; the space also requires lighting and fire safety compartmentalization and sprinklers. However, such costs might be minimized by savings in construction time, and by anticipating reduced costs for alterations to the building as use and needs change.

Contingencies and Escalation. It is not possible to anticipate all the inevitable changes that may be required as the project develops, because every building project is unique. It is critical to factor in contingencies, so you can respond to unforeseen conditions (site conditions or economic fluctuations), and—for possible changes required by the passage of time. Potential changes or escalations in project budgets will be influenced by:

- design development and detailing
- pricing unknowns and complexities
- future escalation trends and market/bidding conditions
- unforeseen conditions and changes during construction
- owner/user discretionary changes.

To be useful, contingencies must be based on previous experience and adjusted at each phase of the project's development. Design contingency covers the discovery process from concept through the bidding of the project. Construction contingency covers unknown conditions or coordination problems on the job site. An owner's contingency may also be maintained to cover discretionary changes as the project proceeds.

Selection of the Construction Delivery Method. There are three contracting arrangements used to deliver construction projects:
1) General Contracting (GC);
2) Design/Build (DB); and
3) Construction Management (CM).
There are variations within each method that reflect the owner's participation, designer participation, whether the contracts are negotiated or competitively bid, and payment provisions (lump sum, guaranteed maximum price, hourly or cost plus). Your staff capabilities, statutory (or procedural) responsibilities, and specific project requirements will provide the basis for informed decisions in this area.

Entire books have been devoted to this subject and there is no room for a complete discussion of advantages, disadvantages, and procedures here. However you should consider the following when deciding the method to be used on your project.

- Determine the range of allowable methods. Some construction delivery methods are not allowed by statute or administrative precedent.
- Analyze capabilities and project goals to determine priorities, e.g. construction expertise during design, cost management, schedule control or phasing, coordination with existing operations, risk management, targeted contractor participation, staff capabilities, and time management.

◆ Match priorities with contracting methods. If you are unfamiliar with the various methods, seek advice from peers who have direct experience with the method in question.

The method of contracting you use will then determine the selection process for the construction members of your project team. Some will be a qualification-based selection, others will be price competitive.

Energy.

Increasingly, institutions are giving attention to energy concerns at every stage in the planning process. Decisions about many aspects of the project, including siting, interior design (use of atriums to bring daylight into the building, materials used), and landscaping, can affect energy use at the time of construction and in years to come. Science facilities consume a large amount of energy and this must be considered as the project budget is developed, including the impact of the project on existing utilities and the capacity of the institution to meet the energy needs of the new facility.

Having a clear understanding about energy costs over the life of the building is also important. There are many design methodologies and studies that can be used to assess ways to optimize the energy efficiency of the building envelope, and/or to use daylighting, passive solar benefits, or wind patterns to maximize the energy efficiency of the building.

By establishing an overall building energy budget that accounts for energy used during building design and construction, equipment cost, and operating energy use over the expected life of the building, you are able to select building systems and materials in the context of broader goals for the project, rather than on a case-by-case determination. Your goal is that all the pieces of the system work together in ways that you have determined are best for your institution now, and that will serve well into the future.

◆

Science facilities consume a large amount of energy and this must be considered as the project budget is developed, including the impact of the project on existing utilities and the capacity of the institution to meet the energy needs of the new facility.

◆

An explicit building energy budget can be a tool to use in researching the potential for utility cost-sharing, to determine if your project would be a candidate for receipt of cost-sharing for energy efficient design, or for cost savings due to reduced energy use at peak hours. (If peak hour demand charges apply, this may be a financial incentive to use time-lag and thermal cooling storage techniques.)

Another benefit of considering issues of sustainable design is that faculty and students can gain a real sense of participation in the planning of the new spaces. There may be expertise among your faculty in regard to energy conservation; if so these faculty should be drawn into the conversation. Student projects, for classes or individual researchers, could be designed to gather and analyze information about climate, or about energy costs of comparative systems and materials that might be used. The symbolism, stewardship, and value of the building in regard to energy can be exploited in many ways for the benefit of the community.

Finally, a carefully thought-through energy plan may have impact beyond the project budget. Certain donors may be attracted to a project that demonstrates clearly that you have taken a broad view about the impact of the building on the institutional operating budget for years to come.

A Worst-case Scenario.

You have carefully defined the facilities program, and your architects have come up with designs that suggest the project will be distinguished and serve the community well for many years. However, it is becoming clear that available or anticipated financial resources will be insufficient, and that you cannot move ahead as planned.

If you are faced with this dilemma, because your fund-raising has not proceeded well, the economic environment has changed, or firm costs exceeded your estimates, (or perhaps because your planning process was not well-in-hand), you need to explore possibilities for reducing the cost of the project, and make a clear decision about how to proceed. Most often, the project shepherd and/or the project manager will take the leadership role in this process of reconsidering.

There are four areas to explore in reconsidering the project:

- space assumptions
- building quality
- cost allocations
- phasing.

Space Assumptions. The first step in considering if or how to reduce project costs is to review your space assumptions, and identify possibilities to reduce the size of the project. Too often during the excitement of the design process, spaces are added which are assumed to be immutable. The project team should return to the documents prepared in the programming and design phases and compare them to the final design and construction documents on which cost projections were made and ask:

- Does the design conform to the facility program in terms of number and size of spaces?
- Were spaces added as part of the design process? If those added spaces are not required for pedagogical/programmatic reasons, can they be removed?

After carefully reviewing your facility program and confirming how it and the designs conform, your next step is to analyze the efficiency of the proposed spaces. Check that the net-to-gross ratio is reasonable. If the ratio is low for your building type, review the various space components in terms of their size and configuration, looking in particular at building circulation and support spaces. It is important, however, to be cautious here: reducing circulation space to achieve a better building space efficiency (and thus lower costs) may be a reasonable action, but such changes have consequences. A tightly designed building may seem cramped and congested; one with generous circulation space may seem more welcoming, friendly, and comfortable.

The net spaces are prime targets for review, change, and adjustment to achieve reduction in project costs, since they represent the largest proportion of the building. Examine the standards and criteria used to determine the size of the individual spaces (offices, classrooms, and laboratories) in your proposed facility. The standards presented in this Handbook represent a range; by using the lower end of the standard rather than the higher, you may be able to reduce the size of the project while still maintaining adequate standards. Ask:

- Are there reductions we can make in regard to sizes for offices, classrooms, laboratories, and community spaces that will reduce cost, stay within standards, yet still be true to our programmatic vision?

It is also essential to review the utilization assumptions (classroom and laboratory scheduling, room occupancy rates, and the relationship between time and space utilization and policies) that undergirded your planning. Ask yourself:

- How would increasing the number of hours per week of scheduled classroom time affect the building size/cost?
- How would a more intense schedule in these spaces affect the wider community?

Some typical targets for space utilization are:

- classrooms (25-35 hours per week, with 60 percent seat occupancy)
- lower-level labs (15-20 hours per week, with 80 percent seat occupancy)
- upper-level labs (8-12 hours per week, with 80 percent seat occupancy).

As stated persistently throughout these pages, the new spaces must be shaped by the ethos and character of the community. (Some institutions choose as a matter of policy to schedule less intensively.) The issue here is what is important to your community.

Although spaces may be considered department-specific, it is also necessary to ask:

- Can individual labs serve more than one department?
- Are classrooms seen as a college-wide resource?

If the college classroom utilization is low, any increase in the inventory should be carefully explored and understood. We suggested in the process of defining the facility program that it would be helpful to prepare a trial schedule for each term for your programmed spaces. Assign courses to classrooms and labs and assign faculty to courses; estimate student enrollments for each. Have you added more spaces than are required? Can perhaps an entire lab be eliminated? Specialized labs with low utilization rates (only one or two courses scheduled per term) should be minimized. Remember to base this trial run on the academic program you are planning for the new spaces—not the programs of past years.

Finally, make determinations about space priorities, sorting out the various assignable spaces into three categories: those that are essential to achieve your goals and objectives; those that would improve the building's functioning; and those spaces that raise the quality of the project from the ordinary to the exceptional. You should ask:

- Have spaces been added in the planning process that could be eliminated or phased, in the interest of achieving a feasible and timely project?

After considering each of these space assumptions from the perspective of conformance to program and priorities, as well as space efficiency, criteria, and standards, you can turn to the second area for analysis and review: building quality.

Building Quality. In the planning process, the cost of each building component was established; at this point you must determine whether some adjustment in building quality would be possible or advisable, and would reduce costs in a helpful way. Obviously, as you make these calculations, you must consider not only costs for initial construction, but also the impact on building maintenance, the length of the repair and replacement cycle, energy conservation, and related operational costs—all items ultimately affected by building quality.

The larger the project, the more likely you will be able to identify some cost-containment measures, assuming costs have been predicated on overall designs that are at least of middle-range quality. Close examination of even small projects may reveal significant cost variables that lend themselves to reconsideration. Some examples illustrate this point: in one project, there was a 40 percent increase in overall project costs when the decision was made to match stonework for an addition to the stonework in the existing structure. By reversing this decision, significant savings were achieved. In another instance, mechanical systems and equipment in the proposed project were sized and selected to serve several buildings that were anticipated to be built at some later date. To meet project budget, systems were planned that only served the current facility.

These examples suggest just some approaches to considering building quality as you consider ways to reduce project cost; your next step is to consider the allocation of project costs.

Cost Allocations. As described earlier, project costs include construction costs, architect and engineer fees, furniture and equipment, and contingencies. You might find higher nonconstruction costs if your project involves custom (not standard) furnishings and equipment, or there are unusual site conditions. If the total cost for your project includes a maintenance fund that is to be established as a percentage of replacement costs, or if a premium is to be paid to obtain the services of a celebrated architect, your nonconstruction costs will also be a larger part of the total costs.

It is prudent at this point, when you are attempting to reduce project costs, to scrutinize the project budget line-by-line. Such an analysis may reveal opportunities for modifying assumptions you have made for using moneys not yet spent, for transferring certain costs to other accounts in the operating or capital budget, and/or for deferring expenditures.

Phasing. One approach to deferring expenditures would be to phase the project. By leaving some space unfinished, or reconfiguring the project so it can be built in several stages, you might be able to proceed although sufficient funds are not yet available. Finishing shell space later (partitions, doors, hardware, electrical fixtures, suspended ceilings, cabinetwork, painting, carpeting, furnishings and fixtures) can result in significant cost postponement. However, such phasing options can have a measurable effect on the morale of those who see unfinished and vacant space. Moreover, the message sent about lack of planning or limited resources to those not familiar with, or sympathetic to, the institution's dilemma may also have considerable financial implications over the long-term. It should also be noted that finishing space at a later date nearly always results in a higher cost.

Stepping back and taking another approach to the design of the building may bring ideas to the fore about reconfiguring your project. Occasionally the project concept may lend itself to a bold stroke—for example, if your project consists of a main structure and wings, with a large auditorium in one wing, the auditorium would be an obvious candidate for a later phase. If there is a science reference library that could be logically broken out of the total scheme, you may be able to integrate it into the larger complex at a later date.

If you have encountered a worst-case scenario, each of the approaches described above should be explored, and while your project has its own surrounding context and circumstances, you may be able to develop a package of possibilities to present to the project team and executive committee (and perhaps to the trustees) as they make decisions about the progress, scope, and character of your project. It will be helpful to all involved if you present such options in the context of your original assumptions and your present analysis of them. If in the early stages of planning, a carefully thought-out facility development strategy was prepared, the options to be considered should be evaluated against that report.

Conclusion.

A realistic project budget is essential to effective cost management of your project. But it also serves other extremely useful purposes. A comprehensive and concise management tool, the project budget is a summary of a multitude of decisions about the scope and quality of a major capital project—your new science facility. The project budget is useful to monitor progress from design through completion of construction to keep the project from inadvertently expanding beyond original parameters, and to communicate about the project with diverse constituencies, internal and external to the institution. It reflects the consideration of both current capital costs and future operating costs, and the institution's commitment to obtain the financial and institutional resources needed to see the project through to completion.

CHAPTER IX: OPERATING BUDGETS

Introduction.

Faculty, administrators, and trustees involved in planning new spaces for science operate on the assumption that these new spaces will provide bountiful benefits to the campus. It is useful to articulate these clearly, to ensure institutional agreement on what these will be to the institution and to the departments involved. The new facility will also generate costs, and it is equally useful to estimate, as accurately as possible, what these additional costs will be to future operating and capital budgets.

Because deferred maintenance tends to grow faster than operating budgets, you must consider also the long-term maintenance and replacement costs brought on-line with a new facility, and make certain you will have sufficient revenues to cover these recurring costs in the future. Such questions about future costs are particularly important in regard to a facility in which costs for the purchase, maintenance, and replacement of equipment and for services are higher than for other campus facilities.

Intangible Benefits and Costs.

In making these estimates, it is critical to consider first intangible benefits and costs which might accrue.

Intangible Benefits. The importance of "community" is a theme of this Handbook, and if your faculty and administrators follow even a portion of the advice given herein, hopefully you will experience improved collegiality as well as agreement on some immediate and future goals for the sciences on your campus. The new facility should also promote curricular innovation and an increase in student and faculty research.

The new spaces can also give you several advantages in intracollegiate competition for scarce resources. The new facility may be instrumental in retaining your best faculty, and in attracting strong new faculty. Your students and faculty will benefit from new instructional and research spaces designed for maximum interaction and learning. Finally, the new facility may add significantly to the prestige of your institution, and attract prospective students from the brightest segment of the applicant pool.

Such benefits are difficult or impossible to quantify, but they clearly add to the luster of the institution and, over time, help create the opportunities and milieu that promote a thriving, dynamic educational environment for the natural science community on your campus.

Intangible Costs. Even a small renovation project will take much time and energy of people on your campus—faculty, administrators, facilities managers, and support staff. A major project is extremely demanding on all institutional resources; it requires considerable time, energy, oversight, and attention, probably beyond what anyone expects at the beginning of planning. This is time and energy away from other campus responsibilities in classrooms, labs, and/or administrative offices; it is a significant cost. If a member of the faculty has been assigned to the project as the faculty shepherd, with release time to compensate for the countless hours spent on the project, the cost of release time becomes tangible and can be a drain on a departmental budget.

If faculty are expected to participate in the planning over and above their other responsibilities, the cost to morale and productivity may be very real. Similarly, the time spent by administrators developing plans for the new science facility and the fund-raising efforts and managing the construction process may exclude or limit serious consideration of other pressing institutional needs. The president and other administrators need to anticipate these time commitments and the pressures they may place on staff and faculty.

For a smaller institution, the cost of a new facility will become a major fund-raising focus and will require gifts and grants from a multitude of donors. These are sources of capital and operating support that become sequestered for this project and thus not available for other campus needs. This may require postponing other capital improvement projects, an intangible cost that also must be considered. Other intangible costs are the disruption caused by a renovation, or by moving from an old to a new facility. In addition to tangible moving costs, faculty bear the brunt of monitoring the move of equipment, personal papers, and artifacts.

PROJECT IMPACT: FORESEEN AND UNFORESEEN

The Allegheny College Experience

In 1987 all members of our campus community, including the trustees, recognized a powerful need for better facilities for science programs on our campus. In part, this recognition arose because of the emerging consensus among faculty about new pedagogical approaches that work. It also grew out of an institutional analysis we undertook in considering the possibility of a major fund-raising campaign. After several years of planning, with persistent, sometimes difficult, but always creative dialogue involving our faculty, senior administrators, and campus planners, we produced a plan for new facilities and for the renovation of existing spaces that made sense both from the educational and fund-raising perspective.

Financing the ambitious facilities projects which emerged from our planning required the same creativity and risk-taking that we had pursued in developing the designs for the new spaces. Ultimately, we put together a combination of gifts, borrowing, and institutional resources that allowed us to undertake the construction of two new buildings and the renovation of two others at a total cost of $22.5 million.

The organizing principles for our planning were several, simple, and critical to our success. The new and renovated spaces should:

◆ foster, to the maximum extent we could afford, hands-on, research-rich experiences for our students

◆ reflect our understanding that science teaching and research are highly social activities

◆ provide generous access to computing in classrooms, labs, lounges, faculty offices, and even hallways.

We anticipated that constructing new facilities and renovating spaces in accord with these principles would have a positive impact on the learning experience of our students. But we did not anticipate the impact of these new spaces on our admissions effort.

I should be clear about the information that follows. Our facility improvements were part of a comprehensive plan which included changes in curriculum pedagogy, investments in computing, and making student research a central component of a liberal arts education. It is therefore somewhat difficult to disentangle the effects of all these activities and isolate the impact of the facilities improvements on the growth of interest in science programs at Allegheny. However, let me try.

While 42 percent of the class that entered Allegheny in 1990 indicated an intention to major in a natural science field or in mathematics, 63 percent of the class that entered in 1994 had that intention. Ultimately, 33 percent of the class that entered in 1990 actually majored in science or mathematics. If the same ratios hold, we believe over 45 percent of the class that entered in 1994 will major in science or mathematics. This upsurge in interest in coming to Allegheny to do science has allowed the college to improve selectivity and quality in the freshman class, while at the same time holding the amount of institutionally funded grant aid for entering students constant for three years. Net tuition revenue has improved significantly, and faculty and students have used the new and renovated spaces to great advantage.

To be certain, undergraduate enrollments in science have risen nationally, not just on our campus, but Allegheny's increases have been above national averages. While there have been great benefits to the college from this growth, there have also been costs. Overwhelmed by student interest, some faculty in the sciences have reverted to a "weeding out" mode; after several straight years of rising retention rates for students in the sciences, the retention rate recently declined. It is a terrible paradox that, having shown how well students respond when science is taught in an investigative manner, our success is being undermined by the overwhelmingly positive student response and the flood of science majors into our new facilities.

In addition, courses in Allegheny's strong humanities, arts, and social sciences departments have suffered declines in enrollment. The next planning projects are focused on responding to acute facilities' needs in nonscience fields, but the short-run difficulties of adjusting to newly skewed enrollment patterns are causing strains.

The positive consequences of Allegheny's investment in science facilities were largely foreseen and intended, but vastly underestimated. The negative consequences perhaps could have been foreseen, but were not. From our experience, we would advise other planners to proceed with all deliberate speed because of the significant impact that new spaces will have on your admissions and educational programs, but take careful note, early in your planning, of what may be the broader impact new spaces may have on your campus.

A Checklist for Impact on Operating Budget.

☐ 1) Unrestricted Revenue Increase $ ____________

☐ 2) Savings in Insurance Costs $ ____________

☐ 3) Savings in Annual Maintenance Costs $ ____________

☐ 4) Science Endowment Fund Revenue $ ____________

☐ 5) Other $ ____________

Total revenue increase $ ____________

Operating Expense Factors

☐ 1) Program and Personnel Costs $ ____________

☐ 2) Building Operation/Maintenance $ ____________

☐ 3) Consumable Supplies $ ____________

☐ 4) Equipment Maintenance $ ____________

☐ 5) Equipment Upgrade/Replacement $ ____________

☐ 6) Building Depreciation $ ____________

☐ 7) Debt Service $ ____________

☐ 8) Other $ ____________

Total expense increase $ ____________

A – B = Net impact of project on annual operating cost $ ____________

Allegheny College Science Complex

Meadville, Pennsylvania

Architect: Ellenzweig Associates
Cambridge, MA

Size:

Biology	55,000
Chemistry	29,000
Renovated	54,000
Future Phase	30,300
Total	168,300

Construction Cost:

New	$13,300,000
Renovated	3,000,000
Future	4,000,000
Total	$20,300,000

Net Square Feet

	Bio.	Chem.
Labs	16,000	11,000
Office	2,000	1,600
Lab Support	6,900	4,500
Other	100	1,900
Total	25,000	19,000

Completion Date:

Biology & Chemistry	Sept. 1993
Renovation	Spring 1996

The impact of Allegheny's new science complex has been powerful. Freshmen indicating an intention to major in science or mathematics increased from 42% to 63%, and the facility has supported innovative teaching and research.

Allegheny's multidisciplinary science complex reflects a commitment to hands-on, interactive teaching. Combining facilities for advanced biology and chemistry as well as a future environmental sciences phase, it also encourages interaction and collaboration among the science disciplines.

A Multidisciplinary Facility

The project is designed as three separate, yet linked, buildings. This arrangement allows flexibility in fund-raising and construction phasing while providing reduced costs due to a shared mechanical facility. It also supports interdisciplinary teaching. Enhancing the overall campus plan, the tripartite scheme creates a new science quadrangle and accommodates the large program without overwhelming the scale of the campus. Two buildings, advanced biology and advanced chemistry, were recently completed, while the third building is planned as a future phase.

The guiding principle behind the design is Allegheny's belief that science instruction must erase the line between lecture and lab, presenting the laboratory as a vital learning tool.

Encouraging Interaction

Reflecting the belief that scientific learning and discovery are promoted by casual interaction, the design provides spaces for informal gatherings. Small lounges are located at the end of hallways where students can gather to brainstorm or use computers. To promote communication among different academic disciplines, the main entrance and lounges are located where the biology and chemistry buildings intersect in a central tower.

Innovative Curriculum

Allegheny has embraced a new curriculum which favors an interactive approach to teaching science, involving students at all levels in independent research and extensive contact with the faculty. Allegheny's major goals were to integrate classrooms and laboratories and to enable students to learn in small, interactive groups with unrestricted student/faculty interaction. The innovative design provides lecture/demonstration rooms adjacent to teaching laboratories, and clustered faculty/student research laboratories.

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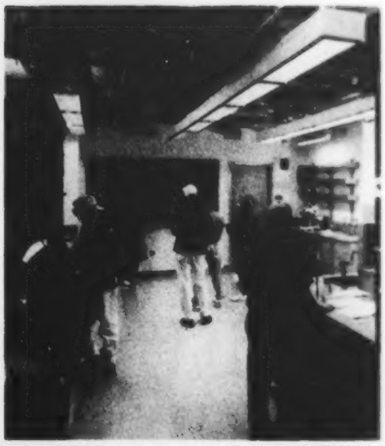
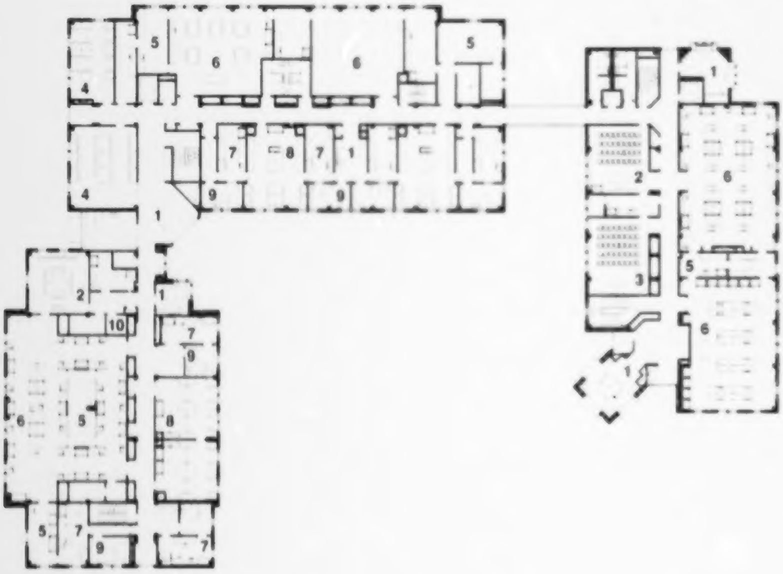


The chemistry teaching laboratories promote the seamless flow of hands-on experimentation and lecture-style teaching by providing "chalktalk" areas and adjacent lecture/demonstration rooms.

Senior research labs are clustered between adjoining faculty research labs and offices, encouraging mentor relationships and creating an enriched learning environment.



Second floor plan

1. *Lounge*
2. *Demonstration/lecture*
3. *Classroom*
4. *Computer laboratory*
5. *Laboratory support*
6. *Teaching laboratory*
7. *Faculty research laboratory*
8. *Student research laboratory*
9. *Faculty office*
10. *Environmental room*

The biology "laboratory/classrooms" provide each student with a complete set of equipment to conduct experiments as well as a full view of the demonstration bench and blackboard.

Three separate yet linked buildings reduce costs while supporting multidisciplinary studies and maintaining an appropriate campus scale.

Operating Budget.

It is important in the planning stage to address the potential impact the new spaces will have on your operating budget. The reasons are obvious: if annual operating costs increase, someone on your campus will have to pay attention to securing an equivalent increase in annual revenue and its source. Further, some building features may have an impact on both revenue and expense. Specialized labs, for example, might become a critical factor in attracting outside revenue for summer outreach programs, or might be utilized for research or technical problem-solving clinics for students sponsored by industry.

Operating Revenue Factors. Improved facilities for science teaching and research often result in a rise in the general level of activity in science departments, with increases in departmental course registration, in numbers of students majoring in the sciences, and in special programs or activities that may take place in the evenings or in summer sessions. This higher level of activity will result in increases in both revenue and expenses. All or some portion of the increase in operating costs will have to be met by an increase in unrestricted budget support.

Some of these increases can be met by savings or income from other lines in the operating budget, including:

- **savings in insurance costs.** Improved science facilities are likely to be safer to operate than older spaces, and the improvements in safety may result in a reduction in insurance costs. One example would be the introduction of microscale organic chemistry labs in place of older organic labs: the shift may reduce insurance expense, along with savings in reagent purchases and waste disposal costs.
- **savings in annual maintenance costs.** Older science facilities are notoriously costly to maintain, particularly if they are severely beyond reasonable life expectancy and if instrumentation is antiquated. You may be able to anticipate considerable savings from the upgrading of building systems (notably HVAC), the provision of adequate fume hoods, and updating of outmoded instrumentation.
- **science endowment fund revenue.** With increased levels of activity and with an increased capital base for annual depreciation of buildings and equipment, it is often necessary to anticipate supporting increased annual expenses by creating an endowment fund. Such a fund is permanent and should be budgeted to increase at the rate of annual inflation based on investment earnings. The surplus of earnings beyond amounts needed to retain the fund's buying power in future periods then becomes available for current needs.

Operating Expense Factors. The reason for providing modern science facilities is to improve the work that is conducted with departmental programs of study and research. Such improvements may require larger budgets for direct program costs, such as faculty salary budgets if student enrollments increase and/or if new programs are added. You must make decisions about the number of new labs and improved instrumentation in the light of the cost of consumable supplies that will be needed to function in the new facilities. In general, estimates based on historical information will become underestimates exceeded as new facilities come on line, and the ambitions of faculty and students alike become more expansive. It is prudent to budget a reserve fund to cushion the operating budget impact.

Other operating expenses that need to be considered include:

- **building operation/ maintenance.** The National Association of College and University Business Officers (NACUBO) along with the Association of Physical Plant Administrators (APPA) have presented convincing arguments that to maintain college and university facilities adequately, you must budget three percent of a facility's insured value annually. This sum is to be spent directly on periodic maintenance or set aside in a reserve fund to be spent later. (This assumes that a building's useful life is about 30 years and that the ensured value will rise annually with inflation in the cost of actually replacing it or of making repairs at a later date.) Furthermore, you should take note that instrumentation in a science facility has a useful life of perhaps six years, requiring an aggressive maintenance/ replacement schedule.[1]

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[1] Calculate maintenance/replacement costs for buildings and instrumentation according to the NACUBO/APPA formula as follows: subtract out the value of instrumentation from the ensured value of the facility, then calculate the three percent for general maintenance on the lower number. Add to that 16 percent of the ensured value of instrumentation to be replaced every six years. Use this sum as an estimate of annual maintenance/replacement cost for the facility and equipment.

- **equipment maintenance.** The cost of annual maintenance contracts on computers and electronic equipment of other kinds is said to be about ten percent of the purchase price. Some institutions elect to add trained maintenance personnel either in lieu of, or in addition to, budgeting for maintenance contracts.
- **equipment upgrade/ replacement.** In addition to the regular maintenance/replacement of laboratory equipment described above, you must budget for upgrading and obtaining new instrumentation on a regular basis. Anticipating future needs for upgrading or replacement of lab instrumentation is most difficult, and ties into the flexibility of the building design and its capacity to accommodate new instruments.
- **building depreciation.** In FY 1991, U.S. colleges and universities were required to include building depreciation in their audited financial statements. For most, the shift in accounting practice is more a reminder to board members that new or improved facilities trigger increased levels of annual depreciation.
- **debt service.** The use of institutional debt for funding the capital cost of facility improvements creates a shift of costs from one-time capital expense budgets to increases in the annual operating budget. It is provident to minimize the amount of long-term debt, and to maximize project capitalization through an aggressive fund-raising effort and by creating operating endowment funds.

Capital Funds and Costs.

Some institutions, by choice or necessity, will select sources of capital project funds which may have significant impact on future operating budgets. The most obvious of these is debt financing, briefly described below. But it can also involve institutional funds, such as endowment or unrestricted reserves, and planned gifts.

Debt Financing. In addition to seeking gifts and grants from alumni and friends of the institution, you should address the possibility of institutional debt financing as you develop your financial strategy. Long-term financing is often used to defray part of the cost of a science facility project, and this option may have appeal for your institution. There are numerous debt financing options to consider, including state-supported educational financing bonds, local government supported bonds, facility loans guaranteed by *Sallie Mae*, Department of Education Title III facility loans, and direct mortgage loans from banks or other lending agencies. The benefits of these arrangements depend significantly on the fluctuation of interest rates, the institution's existing debt obligations, and future repayment options. Each should be investigated thoroughly by experts representing your institution.

Institutional Funds. Institutional funds from plant or unrestricted reserves can also be applied to the cost of your project. Organizational funds, along with bequests and debt financing, are sometimes called "passive" capitalization because the institution does not actively use the facility project as a means of increasing its overall capital assets. Instead, plant funds, unrestricted reserves, surpluses of unrestricted gifts or the return from unrestricted endowment funds are passively applied to the cost of the project.

While few institutions have sufficient reserves or other unrestricted fund balances to finance much of the cost of a major science project, the availability of internal funds can provide important assurances at critical stages in developing a project, for example when making commitments to architectural costs that occur prior to the raising of funds for the facility. Internal short-term loans often do much to move the project ahead to the point of attracting gifts and grants needed to meet bills as they come in.

Deferred/Planned Gifts. Deferred gifts received during your campaign generally are not available immediately for capital projects. However, they are an ideal instrument to create an endowment fund designated to support future operating, maintenance and equipment costs; these may also be tied to faculty support (research, chairs or visiting professorships), or other programmatic needs within the new structure. Deferred gifts do not fund items in the project budget, but their long-term value is that they can assure the success of your planning into the future.

SOME ECONOMICS

A Presidential Perspective

A research-rich, discovery-based, lean and lively curriculum developed in a community of learners "works" at the undergraduate level. The next obvious questions—both at the institutional and national levels—are: What's the cost? Is it cost effective? Here it is critical to distinguish between several units of analysis: cost per student enrolled; cost per course or lab taught; and cost per baccalaureate degree produced. And, it is important to include all costs that can be accurately attributed, including appropriate shares of libraries, computer centers, and physical plant—items normally not allocated to departments, much less to courses, in typical college accounting or budgeting systems.

Studies of the economics of education have shown the payoff from undergraduate education comes with the achievement of a degree, not partial completion of a program (although some data suggest this is not as strong a finding for women). What's important for an institution, a program, or the country is not the intake, or the enrollment level, but the output. Yet, comparative "cost" studies generally examine the educational costs per student enrolled at an institution. Given the systematic differences in costs between lower-level and upper-level undergraduate instruction, and the different attrition rates at different types of institutions, costs per enrolled student will not accurately reflect real differences in the costs to produce baccalaureate degrees. Such studies will systematically bias the results against colleges with high graduation rates.

For example, independent colleges sometimes show higher costs per enrolled student, though some recent studies (e.g., for New York State) indicate no substantial differences in costs per student enrolled between public and independent colleges of arts and science. Since they have higher completion rates, independent colleges (and public institutions with apparently richer resource levels) are probably more efficient, and less costly, when the measure is the cost of producing baccalaureates.

A well-designed study on real comparative costs of producing baccalaureates would be useful; but the above arguments suggest that when one looks at effectiveness and the real efficiency of resource use, the science-active colleges are not as expensive as some would erroneously conclude.

Traditional undergraduate SMET (Science/Mathematics/Engineering/Technology) approaches treat freshman courses as weeding out courses, not recruitment courses—they act "as a filter, not a pump." This often (not always) means low class sizes at upper levels and consequent high cost from low student/faculty ratios. If the productivity of faculty, space, and instrumentation is to be raised, one way to do it is to reduce the attrition rate from lower-level to upper-level courses—one of the objectives of the curriculum and approach at the science-active colleges. The longtime chair of our exceptionally effective geology program is fond of saying, "Geology majors are made, not born." The department treats its introductory course as a proselytizing course for majors and as a result has well-filled upper-level courses. Per graduate, the costs are modest, because the "conversion rate" from elementary to intermediate, to advanced courses is so high.

While we need some further research to confirm, contradict, or modify this mixture of established results and educated guesses, the arithmetic of increased retention and low marginal costs of added students at the advanced levels strongly suggests that changed approaches, even with consequent added costs at the introductory levels, are likely to be worth it.

Creative use of resources to change the way students learn science, and to change in a way that is cost effective, must be a joint effort of faculty, administrative staff, and governing boards. For starters, most traditional budgeting systems in the liberal arts colleges provide neither the accounting information nor the flexibility of decision making, to permit academic departments to know, much less to reallocate, the various costs associated with a department's activities (or those of a course or laboratory). We need to generate the information so that faculty can consider options of trading off alternative uses of resources —space (including improvements), instrumentation, support staff, technical staff, faculty time, consumables, library resources, computer time, access charges, and even travel funds—as they consider how best to help students learn to do science.

This will not be an easy process. The information is not readily available on a cost-accounting basis; lines of budgetary authority generally dictate that the total resources actually employed in instruction are controlled by several different administrative units. Buildings and raw space cannot costlessly be transformed into personnel, animals, or network access fees. Yet, the lessons and insights of the Total Quality Management, or continuous improvement, movement suggest we need to focus on the entire process, not on the individual pieces. This means breaking down the administrative barriers that constrain budgets, involving many different people in the discussion of how best to deal with individual courses, course sequences, or major programs.

If we expect faculty to be creative, we collectively have to allow them the flexibility to do so. Similarly, if faculty expect resources to be made available, they must consider the full range of constraints within which institutions operate. Just as politicians and economists have to understand each other and jointly participate in the making of good public policy, so, too, faculty and administrators have to understand each other and participate jointly in thinking through the best, most efficient, most effective ways of helping our students learn to do science. This collaboration is even more essential than it was in the past because of the rapid and continuous obsolescence of techniques and instrumentation, the continued explosion of knowledge, and the demonstrable concern of all of our publics with the costs of the higher education enterprise.

We discovered...that the most impressive companies we examined—those that were aiming for more than a little improvement and succeeding—were asking themselves a different question from that asked by other organizations. They weren't asking "How can we do what we do faster?" or "How can we do what we do better?" or "How can we do what we do at a lower cost?" Instead they were asking "why do we do what we do at *all*?"

—*Michael Hammer and James Champy, The Reengineering Corporation.*

Conclusion. We end this chapter with a broad view of institutional policies that promote long-term institutional financial health. Plans for a new or renovated facility for science and/or mathematics should be compatible with these sound guidelines.

Institutional policies and practices should:

◆ *systematically plan the allocation of resources to favor programs and facilities in areas that are central to the institution's mission of education and that offer the best opportunities to achieve distinction.*

◆ *build long-term financial planning and funding mechanisms for plant renewal and incorporate these mechanisms into the ongoing financial operation of the institution (as recommended by NACUBO and APPA). Budget funds for equipment maintenance and replacement, or create endowments that can support these functions.*

◆ *review the roles and lines of authority within the institution and assign responsibility with respect to financing and managing facilities. The decentralized organization and shared governance of academia complicate institutional planning, budgeting, and facility development.*

◆ *reduce the cost and achieve better use of existing and potential facilities by improving facility design, construction, and space management and incorporating the best current practices.*

◆ *systematically collect information on the use of space on your own campus and consider space reallocations to maximize space efficiencies.*

◆ *explore opportunities for collaborating, sharing, and using of new information technologies within and among institutions. Sharing is very effective when the research requires limited and routine use of commercially available service-type equipment such as electron microscopes or high-field nuclear magnetic resonance spectrometers.*

Adapted from "*Financing and Managing Academic Research Facilities,*" *Statement of Workshop on "Facility Financing: University Policy Options,"* convened by the Government–University–Industry Research Roundtable (a unit of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine) in 1990. These recommendations were designed primarily for research universities. Yet their utility to institutions of all sizes is obvious, simply because they are sound management practices that protect an institution's physical plant over time.

CHAPTER X: FUND-RAISING

Introduction. The energy and attention required to plan and to raise funds for a new science facility is, of necessity, focused inward: on existing and future laboratories, on the curriculum and pedagogical approaches, on the needs of students and faculty, as well as on existing donors and traditional sources of support. Once the major decisions have been made about the scope, quality, and site of the new facility however, it is important to look outside your institution. Your planning takes place in a larger context; it reflects as well as connects to national efforts to improve undergraduate science and mathematics education. To be effective in securing support for your facility (as well as for your program), you need to address this larger context and be prepared to tell your story based on what contribution the project will make to your students and to society at large.

This is an important story to be telling, especially in places where decisions are made that affect undergraduate science/math education: legislative bodies at the state and federal level, corporations and industries, and private foundations. This is an important story also for those individuals who are potential donors. While a few donors will provide handsome grants or gifts because of their loyalty to your institutions, most major donors either choose to, or have a legal obligation to, contribute to the public good.

Campaign Leadership. A successful fund-raising campaign, whether undertaken to garner support for many different capital and operating needs, or specifically for your new science facility, requires the commitment of many people. Some of you, including science faculty and architects, will have been collaborating for many months in defining the project, one essential part of the foundation for a successful fund-raising effort. Others, including institutional officers for finance and development, will have been working together to determine the financial feasibility of the proposed project, in the context of institutional goals and priorities; this is the other part of the foundation for a successful fund-raising effort.

The arguments that form the rationale for your capital campaign emerge from the discussions that brought you to the point of deciding to move ahead with a capital campaign; thus the early involvement of the president and members of the senior staff in consideration of curricular and campus planning is critical. Development officers, trustees, and faculty have equally important roles to play in preparing for and implementing fund-raising efforts for the new facility or spaces.

Administrators. Securing gifts and grants to bring a major facilities project to a successful conclusion calls for dedicated and enthusiastic leadership at the top—a person or persons who are committed to establishing clear and achievable fund-raising goals, "selling" the project to trustees and other potential donors, and seeing that the right people and processes are in place to achieve fund-raising goals. The executive committee for your facility project includes such persons, who will also have a leadership role in your fund-raising efforts.

In the context of fund-raising, senior administrators:

- review and approve clear and feasible goals for the fund-raising plan, consistent with the institutional identity and mission
- provide the resources (consultants, budget, extra staff, etc.) necessary to achieve campaign goals
- describe the project to all potential donors and to your entire constituency in terms of long-term benefits to the institution
- play a leadership role in soliciting donors (individuals, foundations, and corporations) for gifts and grants to the project.

CHALLENGES AND OPPORTUNITIES

The Development Officer's Perspective

Contemplating, and then planning for and carrying out, a fund-raising effort to secure new or renovated science facilities is at once daunting and exhilarating. Few initiatives undertaken on the college or university campus stir the imagination more vigorously, even as the inevitable issues of cost, complexity, and competing priorities give pause to thoughtful men and women. The renewal or replacement of science facilities occurs most often only once in a generation, so individuals only have this experience one or two times in their academic careers. What are the particular challenges and opportunities for the development officers in this process? In reflecting on my experience over the last decade as the chief development officer on several major science facility projects, some observations come to mind.

Have courage. Such projects, whether they are parts of larger campaigns or are stand-alone efforts, are always extensive undertakings, and thus require a considerable investment in time and work. But the effort is truly justified, as science facilities, and the fund-raising efforts to support them, can energize faculties, trustees, staff and volunteers of a college or university in truly rewarding ways.

Fund-raising success with any project is directly related to being able to provide prospective donors with clear evidence of an institutional endorsement of the proposed facility. It is imperative, then, that there be presidential commitment to integrating fund-raising with facilities planning; the development officer is a central participant in discussions about meeting new space needs. Whether the anticipated science facility is a stand-alone project or a part of a larger capital campaign, the development officer will make her or his greatest contribution because in discussions of what is needed, she or he has become intimately aware of the reasons for elements of the initiative.

Early participation in planning will also enable the development officer to give the best advice about how to select the right volunteer leaders for the campaign and how to make suggestions about potential major donors. In integrating the planning of space and fund-raising, the facility project moves into its proper place in the list of institutional priorities; this will increase substantially the likelihood that the campaign plan will be addressed to the most capable and motivated volunteers and prospective supporters. (Some advice about where to locate prospective donors for a science facility: recent experience suggests that individuals, including those who give through their personal philanthropic foundations, are the most significant pool of potential donors. Although corporate and professionally managed foundations have great interest in and commitment to science and science facilities, experience suggests that the greatest number of lead prospects will be found in the group of individuals with close ties to your institution. And, given the magnitude of these projects, several if not many individual donors will be needed.)

What potential donors (and trustees, presidents, and others within your campus community) want and need is assurance, and then reassurance, that the project is a feasible one, and that it will succeed. Obviously, we can't know that our plans will succeed until they are developed and implemented; indeed the last dollars must be committed before we can be certain.

Once again, a development officer should have courage. This is simply no place for the faint-hearted: if the project is indeed an institutional priority, then all hands must "turn-to" in order for it to prosper. While we cannot forecast success with 100 percent accuracy, this has never been a valid reason for not initiating the preparation for and carrying out of a thoughtful campaign plan for which there are valid prospective donors. Be of good cheer. A development officer should try to make the experience of planning a science facility enjoyable especially since most of these projects involve extensive planning, hard work, and difficult decisions or choices. Finally, have hope. Remember that the planning of a new facility and the community it will foster is an invigorating event for the faculty and administrators involved, as well as a chance to excite a whole campus.

A Checklist for the Capital Campaign for a Facilities Project.

- ☐ Participate in discussions about institutional mission and academic plan
- ☐ Participate in meetings of building users to explore options and opportunities to create new spaces for learning
- ☐ Accompany colleagues on benchmarking visits. Be in touch with other development officers during these visits
- ☐ Review materials on research and teaching
- ☐ Assign development staff and outline responsibilities
- ☐ Establish and coordinate roles of president, vice presidents, other staff, and faculty
- ☐ Create a case statement with full project description and rationale
- ☐ Determine donor recognition policies
- ☐ Identify all potential donors
  - Individuals—trustees and others
  - Foundations
  - Corporations
  - NSF and other prospects at the state and federal level
- ☐ Estimate size of grants/gifts
  - By donor
  - By category of donor
- ☐ Compile/prepare solicitation materials: site plans, floor plans, model, case statement
- ☐ Develop fund-raising schedule/calendar
  - Solicitation deadlines for individuals
  - Proposal deadlines for foundations and corporations
  - Deadlines for printing and mailing publications, brochures, and other campaign materials
- ☐ Coordinate with other campaign/fund-raising deadlines
- ☐ Plan and schedule programs/events/dinners/open houses
- ☐ Plan and schedule announcements/press releases
- ☐ Coordinate fund-raising schedule with project design and construction schedule
- ☐ Monitor each stage of the fund-raising effort
- ☐ Continue to meet with project shepherd and project committees
- ☐ Keep initial and major donors informed of progress
- ☐ Monitor donor recognition possibilities
- ☐ Plan the ground-breaking and the dedication ceremonies

Reed College Hauser Science Library

Portland, Oregon

Architect: Zimmer Gunsul Frasca Partnership
Portland, Oregon

Size: 41,630 GSF New Construction
9,860 GSF Renovated Area

Construction Cost: $4,900,000

Completion Date: August 1989

Holdings: 375,000 volumes
1,500 periodicals

The Reed College Hauser Library is both the academic and social center of the campus.

The ZGF-designed Hauser Library addition expands and centralizes a scattered group of science libraries on the Reed College campus. Like most small colleges, there was also a need for a variety of other spaces, including classrooms and faculty offices for departments of math and art history, an art gallery, media and language labs and an academic computer center. All of these elements were made part of the program for this 41,630 square foot addition and related alteration of the existing library.

Contextually Responsive

This project is the second addition to a building originally designed in the 1920's by Pietro Belluschi of A.E. Doyle & Associates. The first addition was designed in the 1960's by Harry Weese. Founded in 1911, the Reed College campus is of English Elizabethan Tudor architecture and the arrangement of the founding buildings was inspired by the quadrangles of St. John's College Oxford. Maintaining the character of the campus, the original library building was important to the faculty, students, and the architectural design team.

Design Solution

The design solution combines all program components within a five-story brick and cast stone building (two levels are below grade). The addition reflects the scale of the original building and campus, and ties together the previous building components with new library, classroom, and gallery uses. The addition also provides an important and direct link to the science departments, located in an adjacent building, through a sheltered passageway. This passageway also serves as a gateway connection from the main parking area to the new library entrance. The former west entrance to the library was remodeled into an enclosed bay window sitting lounge and maintains an orientation onto the Great Lawn. Exterior walls of the library addition are of custom brick, laid in an English bond pattern to match the existing Hauser Library.

A covered connection to the Biology/Physics Building makes the library an integral part of the science complex.

Function

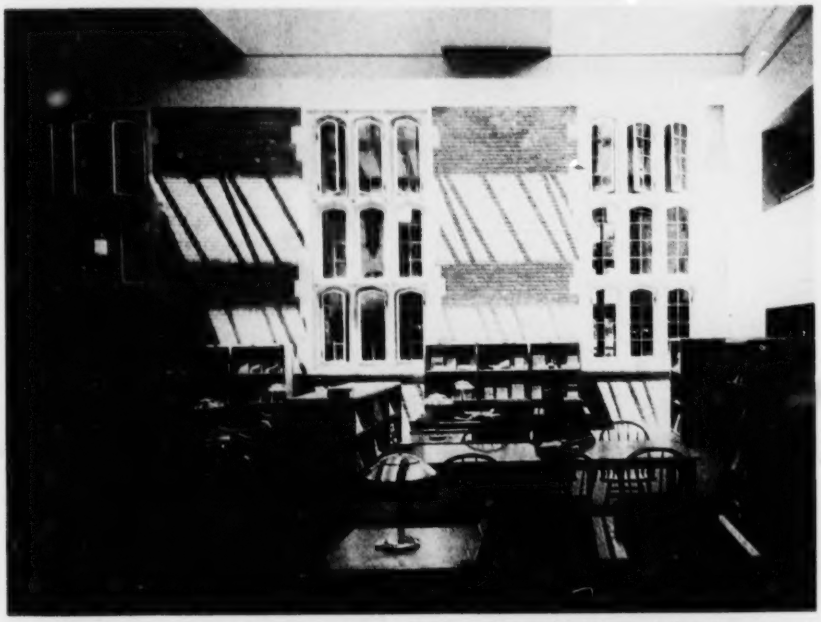
The library is not only the intellectual base of the student body but it is also the social base. All central functions—library, gallery and classrooms—share a common lobby, which serves as a gathering place for students. This plan provides the security required for the library, while allowing the other elements to remain outside of the secured area. A circulation stair and elevator off the lobby provide access to all areas outside the secure library zone. Seating areas within bay windows are provided at each floor of the stairway as a place for students to meet and study. The new addition provides individual study spaces for senior thesis students and all levels of the building are available to the handicapped through the use of an elevator or handicap lift.

At the center of the library, a former exterior courtyard was enclosed to create a two-story skylit reading room. The original brick, exterior wall, with limestone window tracery, was preserved and highlighted by skylights in the new unified science reading room. These skylights also transmit natural light into the original Hauser Library reading rooms.

BEST COPY AVAILABLE

The covered walkway connecting the Hauser Library with the biology/physics building provides a gateway to the complex.

The Hauser Library and connected science buildings respect the original structures and character of the campus.



The two-story reading room incorporates the exterior wall of the existing library as a central focus.

Energy Efficiency

Energy efficiency was a significant consideration in the building design, choice of materials, and construction. Insulated glass was used throughout the addition and renovation. Skylights and clerestory windows reduce the daytime lighting needs in the reading room. The mechanical attic space reduces heat gain and loss through the upper levels of the library addition.

Operation

Construction took place during the summer months to minimize disruption of the use of the library. The library did operate throughout the construction process. The library is now open to students from 8 A.M. to 2:30 A.M. Monday through Thursday, and until midnight on Friday and Saturday throughout the academic year.

Faculty. Institution-wide commitment to the need for a new science facility is more likely if faculty have taken the lead in making a strong and convincing case internally—to development officers, other administrators and faculty—about its significance. Particularly at smaller institutions, such faculty leadership and campus-wide commitment is critical, as the effort to raise the significant funds for a science facility may mean deferring fund-raising for other institutional priorities for a considerable period.

Science faculty, with responsibility for identifying specific immediate and long-term physical space needs, also have the obligation to articulate to the external community how the new facility serves the entire educational program. Faculty involved in this project must remember that neither their humanities colleagues nor prospective donors will be persuaded about the benefit of the project by tales of roofs that leak or ventilation systems that do not ventilate. Focusing on the positive impact that the new spaces will have is key to garnering support.

Faculty can help with the development efforts by:

- **identifying alumni who would be potential donors and/or spokespersons.** Distinguished alumni scientists may be profiled in foundation proposals, or perhaps invited to serve on an advisory committee for your curricular planning or for the planning of your new spaces.
- **making presentations on *what works.*** Describing innovations in teaching or on faculty/student research projects at meetings of trustees and/or alumni councils help sell the project.
- **providing informative background material.** Examples of student research projects or descriptions of faculty research can be incorporated into grant proposals and campaign materials. Such material can serve as the basis for an article in the alumni news bulletin, or in the local press; it helps the development office tell the story of the project from the perspective of the user.

Development Officers. Development officers have the responsibility to be informed about external sources of funds and the probability of raising them. They have asked: *"Can we realistically raise the necessary funds?"* again and again over the past months as your planning proceeded, to different audiences inside and outside your institution. This questioning is part of the fund-raising feasibility study that parallels the assessment of needs and priorities in regard to curriculum and campus.

Fund-raising Activities.

Once the decision has been made to go ahead with the campaign, development officers move into the preplanning stage, in which they prepare lists of potential donors, research and rank them, and propose a timeline for planning and fund-raising that is consistent with the needs and timeline for the project. At all times during the planning and implementation of the campaign, the development officer (or officers) keeps in close touch with the project shepherd and project manager, and continues to work carefully with institutional leaders to coordinate fund-raising for this specific project with other long-term institutional advancement goals.

The Plan. The first formal step by development officers is to prepare a fund-raising plan that details the host of activities needed to secure support for the proposed facility, with a schedule of deadlines for accomplishing these tasks. (As important as this plan is, remember to be flexible and prepared to adapt when things go differently than planned. A rigid plan is likely to develop significant cracks!) The fund-raising plan is a short, straightforward operational scheme that includes a listing of prospective donors (foundations, corporations, individuals), the timeline for development of campaign materials and the solicitation (or submission of proposals), and the likely amounts that can be expected from major donors and categories of donors.

Listing all prospective donors in one place is critical. By ranking prospective donors by size of request, you can begin with those most capable of making the largest gifts. If the lead gift is to be requested from a foundation, you might consider having one or two smaller gifts in-hand that demonstrate leadership commitment. In some instances, a large foundation grant must be triggered by a commitment of institutional sources (undesignated campaign or trustee gifts, bequests, accumulated plant funds). An institution with close ties to industry will include corporate solicitation at the early stages in its plans. For some small liberal arts colleges, the project may be a way to open doors to selected corporations, but the amount of corporate support received may be small relative to foundation and individual grants and gifts.

As it is being drafted, the fund-raising plan is circulated to administrators, trustees, development staff and perhaps others for their advice and counsel—and approval. Once approved, the plan provides the outline for the development of the campaign/project case statement, and sets the stage for many months of intense, but rewarding, activity.

The Case Statement. The case statement is a very important document. It is where you articulate your vision of how the new science facilities will improve science, teaching and research and how this vision fits within the institution's long-range goals. The case statement is really a story about the past, present and future of your institution, a chronicle of the planning and dreams that brought you to this point presented in such a way as to capture the attention and interest of prospective donors.

The case statement brings information from the project committees, faculty, department chairs, deans, architects, and administrators together into a complete argument; it summarizes information needed in discussions with prospective donors, and provides text and ideas for proposals to foundations, and for brochures, press releases, etc. The case statement is a time-consuming document to prepare; it requires special expertise and experience to do it well. It may be that a consultant is brought in to assist in the development of the case, in the context of planning the campaign.

In the case statement, you:

◆ **detail how your curriculum, campus, and community will be enhanced.** Donors want to know how the new facility will serve your science departments and improve teaching, research, and learning generally; how the new structures and spaces will contribute to a campus that is more open and hospitable. Prospective donors need to have a sense that both your academic plan and campus plan are coherent. They want to support a distinguished project, one that is academically and fiscally sound.

◆ **present a clear picture of cost.** Donors need to know the full project cost, and what the impact of their gift or grant will be on the total fund-raising effort. Major donors are keenly interested in the institution's plans for raising the total sum needed (in addition to their own gift or grant) to build or renovate science facilities, and appreciate being informed of gifts and grants already received.

◆ **give evidence of productivity.** Donors reward excellence; they are interested in knowing about faculty research, awards and honors, about alumni who have gone on to distinguished careers, and about research projects and published papers of current students and faculty. Short profiles of individual faculty, students, and alumni make your case come alive. If you are planning to solicit regional or national corporations, have complete data on your alumni who work or have worked for the company in recent years.

PREPARING A COMPETITIVE PROPOSAL

One Foundation Officer's Perspective

Evaluation of the relative merits of science facility proposals should reflect a combination of factors, particularly if competing requests are numerous at a given foundation and if competition among proposals is therefore keen. In such a context, the successful proposal must argue the merits of its case on a number of levels, and each type of argument must be firmly presented if the proposal is to compete well.

Proposal writers should remember this is an occasion to present the strengths of your case on levels that are project-specific, science discipline-wide, and institution-wide. More than other types of funding, capital funding is a long-term commitment and therefore oriented to institutional leadership.

In quick summary, the proposal first should present a statement of the project's expected functional, programmatic value and then information to demonstrate that those benefits will be successfully delivered. Second, the proposal should set forth a clear statement of the track record of the sciences on campus in the numbers of students annually taught, the numbers of graduates by discipline, and faculty accomplishments in educational attainment, research, outreach, or other special programs. Third, the proposal should outline the track record of the institution in overall enrollment, numbers of graduates, financial administration, and recent accreditation review. If one of these levels of argument is neglected or contains adverse information, the competitiveness of the application will almost certainly be limited.

In decisions about competing requests, it is often easier to say why proposals are declined than why they are funded. Often applications fail to make an effective case for foundation support because the connection between the project and stated priorities of the foundation is not made clear. Often too, the timing of proposal review is not favorable due to early and incomplete, lacking needed equipment allocations, failing to include contingencies appropriate to the stage of architectural plans, or not plausible in the light or prevailing construction costs. Institutions sometimes attempt to construct new buildings to revive programs (rather than planning new facilities deliberately to accommodate programs of proven success with students), and such an investment of capital funding cannot be well justified.

Capital requests that are reviewed during significant changes in institutional leadership are also not well received, just as the early stage of major strategic planning is not a friendly context for capital development. If board leadership and other sources of major gifts have not firmly committed the leadership needed to compete the project, a plausible context for a foundation gift cannot be established. If recent years have seen operational deficits, if stability has not been achieved in annual fund-raising, if serious accreditation concerns are outstanding, the time may not be right for raising capital funding.

Problems of coordination of the project itself can prove decisive, especially if it is not clear how the two project timetables (architectural design and fund-raising) can be drawn together successfully. Institutional trustees will sometime assert that a guaranteed cost ceiling has been established and, no matter what the impact on diminishing the functional value of the facility, costs will not be permitted to exceed that ceiling. Such insensitivity to program impact usually has a chilling effect on proposal review. Of course, the solution to this very problem is a key goal of Project Kaleidoscope and of this Handbook.

◆ **position the new facility within long-range plans for total campus renewal, and within long-range plans for overall support for science education.** For instance, by bringing together plans for science endowments (for professorships, research, equipment and/or maintenance) with plans for the new facility, you can outline a 10- or 20-year plan for strengthening the sciences. Donors to science facilities want to be assured of the importance of this project within the overall set of institutional priorities you have established.

In addition to connecting your project to particular institutional goals, in the case statement you should also speak of how your project serves larger societal goals. As you develop the case statement, address questions such as:

- Why do undergraduate students, now and in the coming decade, need to understand how science and technology have an increasing impact on all of life?
- How will new spaces play even a small part in preparing our students to be the next generation of leaders? What understandings and skills will they gain as members of a natural science community on our campus?
- Where do our students come from, and where do they go when they leave our campus?
- What kind of spaces for scholarly activity do faculty need to remain vital as scientists and to have rewarding careers in classroom and lab?

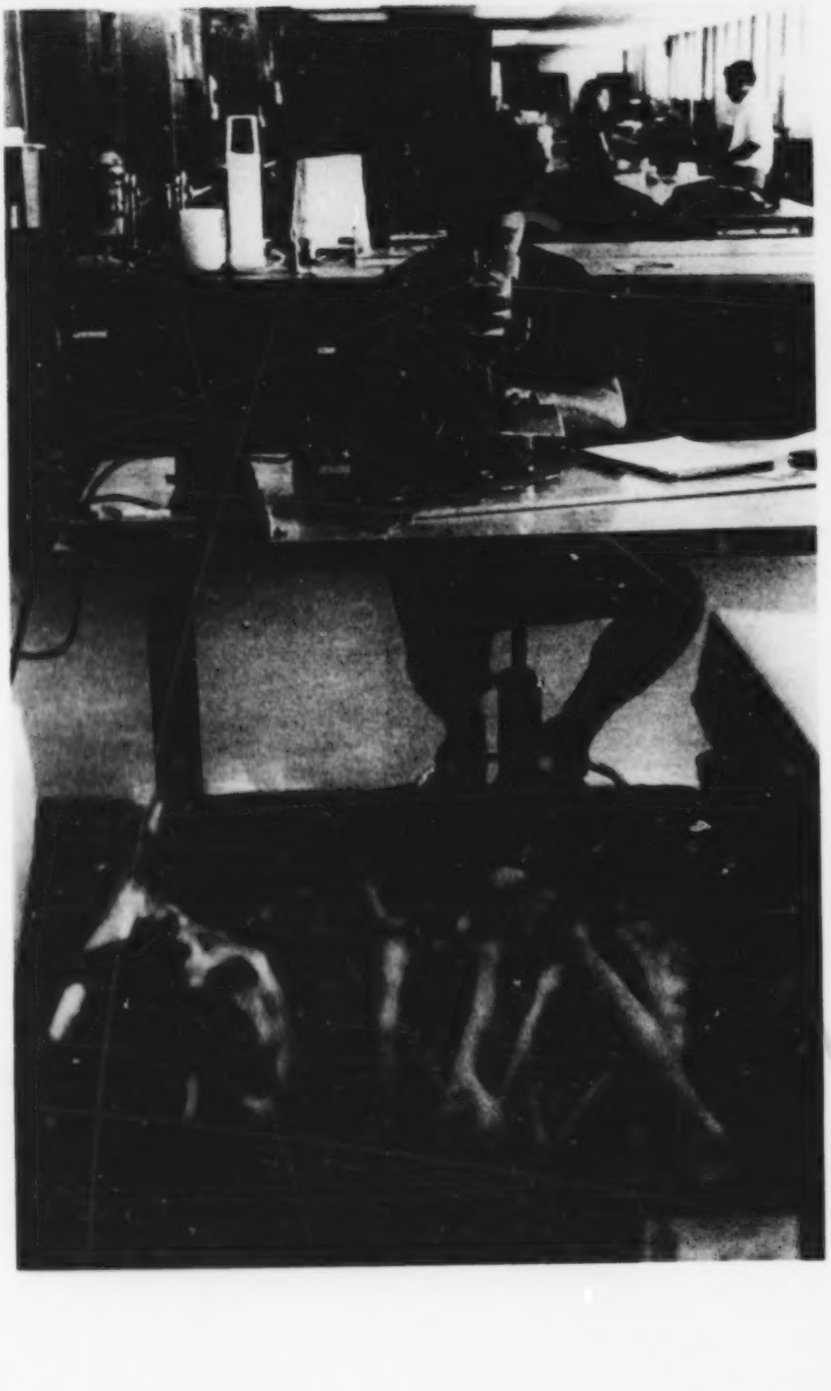
Finally, and most important from the perspective of both alumni and the other groups of potential donors, your case statement should address the role of science in liberal education, documenting some of your earlier discussions about goals for your educational program, about the purpose of the enterprise, about *what works*.

Your case statement should focus on the future: for your students and faculty, your institution, and for society.

Strategies. Your fund-raising plan will also include different strategies to be used to generate the highest level of giving from all categories of donors, including:

◆ **drawings and models.** It is useful and persuasive to have at least preliminary floor plans and perhaps a model at the point when the primary donors are first approached. This may mean that a considerable number of preliminary design decisions have been made, and that the architects have been selected and are working on the plans before any funds have been requested or received. The up-front expenditure for this preliminary design work may well be worth the risks involved, but this is a consideration (and a decision) which you must make very early in the evolution of the project. In addition, photographs of the model may be used on brochures and in proposals.

◆ **lead gifts.** One or two lead gifts from trustees or foundations will provide momentum and encourage other donors. These initial solicitations may be key to the project's ultimate success, and because they often are for substantial sums from donors close to the institution, they must be managed with great care. (In a few, the offer of a substantial



gift from a lead donor may be the initial impetus for your planning.)

Significant early contributions from those who are closest to the institution and to the department(s) involved are strong evidence of the importance of the project; such leadership gifts may stimulate others whose interests are not as immediately engaged. In most capital campaigns, 80 percent of contributed funds arise from 20 percent of the donors. Large gifts from board members may set the pace for others, provide necessary major commitments, and thus assure the feasibility of the fund-raising endeavor, even at a stage when the project scope and cost may still be in flux.

◆ **challenge grants.** A challenge grant from an individual or a foundation can be helpful at all stages, but particularly to bring the process to a successful closure. A challenge grant may draw individuals into campaign participation who have never before given to an institution (new alumni, for example) or encourage giving at a higher level. You must have specific strategies in your fund-raising plan to secure the initial "challenge" grant from a single donor or foundation, and to secure the matching gifts and grants from other individuals and groups.

◆ **advisory groups.** Your campaign may be tied to a capital campaign which seeks gifts and grants for several purposes, or it may be tied specifically to this facility project. In either case, faculty and administrative leaders, development officers, trustees might work together to develop a visiting committee of distinguished scientists, perhaps alumni, whose names and prestige add credibility to the project.

Traditional fund-raising methods, including phonathons, general and targeting mailings, and regional campaigns may be a part of the total effort. For example, you may provide alumni an opportunity to earmark gifts to specific rooms or spaces within the facility, and/or for an endowed fund for equipment purchase and maintenance. Broad categories of individuals may be mailed a targeted solicitation toward the end of the campaign, showing how their gift (new or additional) will benefit the project and thus, the institution.

Sources of Gifts and Grants.

Every endeavor to raise funds must also raise friends. From the very first weeks of thinking about a possible science facility project, you should have in mind how to use the project to raise both friends and funds in ways that will be of long-term benefit to your institutions. Sources include:

◆ **foundations.** Private or corporate foundations, regional foundations, charitable trusts, and some community foundations are valuable sources of capital grants. While only a few national foundations regularly give to facility projects, many more operate within their geographical region or support a specific list of eligible grantees. Beyond the value of their grants, foundation support implies an endorsement of the project which can help open doors to other major donors. In approaching foundations, you must research them carefully, and develop proposals that meet the foundation's guidelines precisely. (Small family foundations and trust accounts are best researched and solicited in the "individuals" donor category.)

◆ **corporations.** Corporations, which can fall into either the larger and smaller gift-potential category, can play a variety of roles in your strategic fund-raising plan. Major corporate gifts may, of course, arise from board members with business connections. Those involved in high-tech enterprises are prime prospects, and they may be motivated by naming opportunities that will bring the name of their firm positive public attention.

In some campaigns, formation of a corporate advisory board can have numerous benefits, both for the immediate purpose of raising funds and for the longer-term purpose of developing important contacts for your institution. (Gifts-in-kind, which may include major moveable equipment, deeper than usual discounts on purchases of new items, or "used" corporate equipment or furnishings, can expand the value of corporate gifts made to your building project.) Institutions that have existing ties with corporations will want to capitalize on these connections and carefully structure their corporate solicitation plan.

◆ **government grants.** Government grants should be considered as possible funding options, with particular attention made to the NSF Academic Facilities Modernization Program. Some states have special science and technology incentive programs that may provide capital grants for facilities (often through issuance of public debt instruments that are the obligation of the government entity, not of the receiving institution). In other cases, state incentive programs provide funding for purchase of equipment, facility planning, or other costs associated with the project even if construction costs are not eligible.

Keep alert to the current status of the National Science Foundation's Science Facility Modernization program, which provides support for the modernization of existing space used for research and/or research-training. (In rare cases this program supports costs of construction of replacement space.) With careful planning, these grants can be integrated into broader fund-raising plans, as well as give assurance to other donors that the major national funding agency for science has assigned high priority to this project.

Development officers coordinate the involvement of institutional leaders, including trustees and faculty, in the cultivation and solicitation of these various categories of potential donors.

Benefits.

The goals of your fund-raising campaign will be developed by faculty, departments, deans, and the administration, based on an assessment of the current and future capital needs of your institution. It will be persuasive to prospective donors, if you can document, from carefully kept records of your earlier and ongoing discussions, that the science facility project is among or at the top of the list of your most-pressing capital needs, and that it has widespread campus support.

One benefit of a campaign is the clarity it can bring to the articulation of institutional goals and priorities. There are other benefits; campaigns, which have become a way of life for most colleges and universities (they are either getting ready for one, in one, or wrapping up the last one), are a means to husband the time, energy, expertise, and experience on your campus most productively. During a campaign, trustees may be actively involved as donors and volunteers; the development office may have expanded staff to manage increased volume of work; your president and other top administrators will devote a considerable amount of their time and energy to achieve your goals. When your campaign "comes together," decisions about prospective donors, solicitation procedures, and/or designation of gifts will not be *ad hoc*, or made in isolation by single individuals; rather such critical decisions will be made based on the communal vision of the future of your institution.

Conclusion. The energy and attention required to plan and to raise funds for a new science facility is, of necessity, focused inward: on existing and future laboratories, on the curriculum and pedagogical approaches, on the needs of students and faculty, as well as on existing donors and traditional sources of support. Once the major decisions have been made about the scope, quality, and site of the new facility however, it is important to look outside your institution. Your planning takes place in a larger context; it reflects as well as connects to national efforts to improve undergraduate science and mathematics education. To be effective in securing support for your facility (as well as for your program), you need to address this larger context and be prepared to tell your story based on what contribution the project will make to your students and to society at large.

This is an important story to be telling especially in places where decisions are made that affect undergraduate science/math education: legislative bodies at the state and federal level, corporations and industries, and private foundation. This is an important story also for those individuals who are potential donors. While a few donors will provide handsome grants or gifts because of their loyalty to your institutions, most major donors either choose to, or have a legal obligation to, contribute to the public good.

Your campaign to raise millions for science facilities is an opportunity to communicate with those who already support your institution; it is also an opportunity to reach out to those with the potential to be major donors. You will have a strong case to make and a surprisingly large number of individuals will be willing to listen. Your fund-raising plan will therefore include proposals to individuals, government agencies, foundation and corporations that are most likely to be enthusiastic about and provide funds for your project; it should also include a tier of well-placed prospects—people and groups you want to learn about your institution and your plans for the future.

Coordinating a complex fund-raising project is a multifaceted juggling act, with at least two more balls in the air than you can possibly catch. The pressures to fulfill the immediate goal is intense, and finding time to address a larger perspective of your overall institutional advancement goals will tend to get set aside. We argue that your immediate goal will be easier to achieve if you also make the effort to connect your individual project to larger societal goals.

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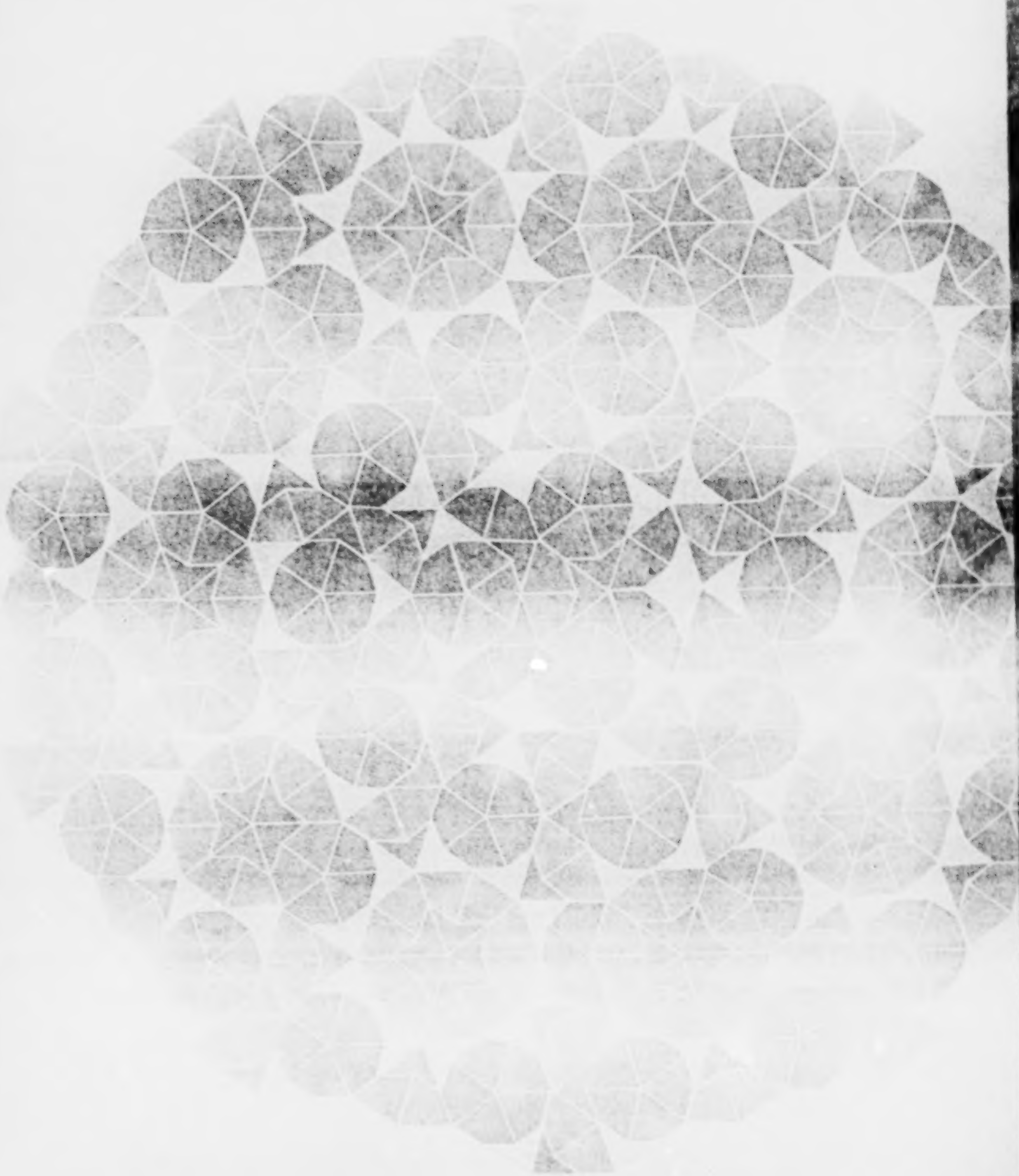

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Once the dedication celebration is over and the classrooms and labs are in use, our hope is that you close the loop on the planning process and begin again with discussions about mission and about the future for undergraduate programs in science, mathematics, and engineering on your campus. The new spaces should reflect the deliberations you have had on such issues over the past months and years; they should be a catalyst for continued dialogue about the purpose of the enterprise.

To seed such conversations, we end this handbook with a kaleidoscope of perspectives. Some of these are solicited reflections and predictions from the PKAL community; some are taken from writings and speeches of other national leaders in science, education, public affairs, and some from students engaged in programs that work. Together they present a vision of a future that to some extent is already present: on campuses across the country distinctions are being blurred between disciplines and departments; connections are being made, within and beyond single courses, departments, and institutions to improve the learning environment for students.

Most of these perspectives do not specifically address issues in regard to space use, but the ideas presented—about restructuring and reengineering faculties, departments, and administrative structures; about stressing science as a liberal art as a sphere of study essential for all students; and about accommodating technologies in ways that serve students and faculty—all have implications for the shaping and reshaping of spaces and structures for natural science communities in undergraduate settings.

The process of planning will be a defining one for your institution if it sets the stage for ongoing conversations about the purpose of the enterprise, on your campus, with students as well as other colleagues, and with the larger group of individuals and institutions committed to a strong undergraduate natural science community.

What we call the beginning is often the end and to make an end is to make a beginning.

—T. S. Eliot.

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In the modern liberal arts, the sciences set the pattern and pose energizing challenges for the other disciplines. The entry of the sciences into the college curriculum a little over a century ago dramatically transformed and revitalized undergraduate education. Today, in part because the sciences intimidate most who are not engaged in them, their centrality is less well appreciated. Properly taught as fields of inquiry, of methodical, collaborative exploration and discovery—they catalyze the liberal arts across the breadth of its fields and focal concerns.

Before the Civil War, the curriculum of every American college (there were as yet no universities) was comprised of a series of studies uniformly prescribed by year. Latin, Greek and mathematics figured most prominently in this fixed curriculum. Instruction consisted of several hours of recitations each morning of rote recital of material from assigned texts, followed by exercises in elocution and disputation in the afternoon. The explicit rationale for this education was one of developing mental faculties, with the aim of strengthening the capabilities of the mind through something like mental calisthenics.

What little science was accorded a place in this curriculum (natural history and natural philosophy) was descriptive and taxonomic, and largely taught in the same stultifying manner. Most active science was conducted outside institutions of higher education in independent, largely amateur, laboratories and local societies of natural history and of arts and sciences.

Over the course of the 19th century, the sciences became organized as distinct disciplines, sustained research became more widespread, and the sciences came to be more essential to advances in technology and industrial growth. Concomitantly, these disciplines insisted on a more substantial place in the college curriculum. At first they were accorded a separate and secondary one. Many colleges began offering a "scientific" course of study, equally prescribed and parallel to the long-standing "classical" course. Others created separate institutions such as the Sheffield School at Yale and the Lawrence School at Harvard. These scientific courses tended to employ the same manner of instruction, but lectures soon began to replace recitations because textbooks could not keep up with the pace of discovery. Increasingly students were drawn into the laboratory, into hands-on involvement with the processes of experimentation and discovery.

With the sciences very much in the lead, a new liberal arts curriculum took shape late in the nineteenth century, one organized around two dozen or so distinct disciplines, a wide range of elective choice for students within these fields, requirements for core or common learning to insure a broad base, and requirements (generally a major) for study in depth in some field. The sciences had achieved a secure place in all three components: core, major, and electives.

We face change on many fronts, and change characteristically engenders both opportunity and uncertainty. The end of the Cold War has transformed international relationships and security needs. Highly competitive economies have emerged in Europe and Asia, putting new stresses on our private sector and on employment. The ongoing information revolution both enables and demands new ways of doing business. During the 1980's, our federal budget deficit grew rapidly, constraining crucial investments for the future. Our population diversity has increased, yielding new opportunities to build on a traditional American strength. Health and environmental responsibility present increasingly complex challenges, and the literacy standards for a productive and fulfilling role in twenty-first century society are expanding beyond the traditional "three R's" into science and technology.

As our institutions anticipate, manage, and respond to change, we must continue to focus on the enduring core elements of our national interest: the health, prosperity, security, environmental responsibility, and quality of life of all our citizens....improved science and mathematics education is now recognized as a strategic imperative for our individual and collective futures.

—Science in the National Interest, Office of Science and Technology Policy, The Executive Office of The White House, 1994.

It is self-evident that we live in a society dominated by science and technology and it is improbable that a person can adequately cope or be truly "liberated" while being largely ignorant of them—such ignorance being the handmaiden of the fear and estrangement that seems so pervasive in contemporary society Thus, science and technology must become part of the liberal arts disciplines, now mainly thought to be in the humanities, that are deemed necessary for an effective and satisfying life. Such a goal cannot be achieved without a drastic revision of how science and technology are taught.

The task now to be addressed is to define a level of literacy appropriate for an intellectually inquisitive person and then suggest how that level might be achieved. Cultural literacy, broadly defined, is knowledge of civilizations: their art, music, literature, history, political and social systems, economics, science, technology, philosophy, and religious and ethical beliefs. A culturally literate person need not have read all the books, listened to all music viewed all objects of art, and visited all regions of the world. Nothing more is possible than a knowledge of some of these things and an ability to relate the newly encountered to what is already known personally....Literacy in science and technology consists of the ability to understand, in a general way, the natural and manmade worlds. One should be curious about any observed phenomenon of these two worlds, have some degree of understanding, and know how to obtain deeper understanding.

—*John A. Moore, Cultural and Scientific Literacy, Molecular Biology of the Cell, 1995.*

The most fundamental aims of a liberal arts education did not change. They remained preparing young men, and in time young women as well, for all opportunities and responsibilities that human endeavor might pose for them: in Whitehead's phrase, to give them all the uses of themselves. The new curriculum did have quite a different approach to accomplishing this. No longer would students be simply asked to master a fixed corpus of knowledge. The focus would now be on preparing students for a life of inquiry, for posing serious questions and devising well-conceived strategies for finding answers to these. Faculty at colleges and universities were now expected to be scholars and researchers as well as teachers, and as teachers they would be leading students into the methods of inquiry and discovery. Libraries were no longer simply reference rooms for housing the required texts; they became settings for pursuing research—requiring expanding collections of journals and monographs, and aids for searching through these. Students began to write papers and pursue independent projects.

It was the sciences which set the pattern for this radically new approach to liberal education and they continue to constitute the dominant image of a field of knowledge in the liberal arts and sciences. We should appreciate several characteristics to grasp their fundamental vitality. Good undergraduate science education is:

◆ **active.** Science is an activity, a restless, open-ended, skeptical, and methodical process of inquiry and discovery. Students must grasp how science progresses through active involvement.

◆ **hands-on.** Among the chief frustrations and joys of science (and the joy because of the frustration) is experiencing the recalcitrance of the world. Observations may be quite different than predicted, for example, and then, what can be equally surprising, just what one expected. It is important that students have both experiences at first hand.

◆ **collaborative.** The restless, inquiring spirit of science is nurtured by shared effort: ruminations, problem-solving sessions, hallway and lab conversations, colloquia and seminars. A great deal of the excitement, as well as of the productivity of science results from shared inquiry and shared discovery.

More and less self-consciously, other scholarly disciplines have established themselves in relation to this dominant image of a methodical, empirical, hypothesis testing approach to knowledge. It is not that the other disciplines have all simply copied the sciences. Rather, the sciences constitute the dominant image of serious knowledge and inquiry, and other disciplines feel compelled to establish themselves in relation to this.

Beyond providing the dominant image of inquiry, a number of core concepts in the sciences have also catalyzed the liberal arts in this century. Natural selection, equilibrium, entropy, relativity, the uncertainty principle: these and a score of others have provided challenging and suggestive ideas across the liberal arts fields. This borrowing sometimes raises suspicion, even contempt from scientists who are troubled by instances which show failure to grasp precisely the concept as scientists grasp them. The borrowing, the transformation, and the subsequent cross- and multidisciplinary conversations are nonetheless important: the sciences constantly tantalize and provoke other fields. It rightly falls to these other disciplines, particularly those with concerns for interpretation, to make broader sense of the borrowed ideas, to weave them into the fabric of our culture.

While the sciences, properly taught, are vitally important for the liberal arts, it is equally important that the sciences be taught in the company and context of the humanities and social sciences. The liberal arts must remain focused on human purposes, human capabilities, and human understandings. Taught separately, the sciences risk losing touch with such wider inquiries and discussions.

The other liberal arts are immeasurably richer today because of the liberal sciences, but a difficult challenge for us all is to find ways for the sciences and the other realms of knowledge to continue spirited and fruitful conversation with one another.

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A KALEIDOSCOPE OF THOUGHTS ON THE FUTURE

We could seat children in rows and talk at them when we were going to expect them to stand in rows in factories and mills. If they are to be prepared to be the workers and thinkers of the twenty-first century, they must be experiencing the world directly, guided by teachers who act like coaches in helping them to formulate and answer difficult questions. Now we must give our children the opportunity to use and strengthen every creative and inquiring instinct they possess. We know that they must learn to work cooperatively, to write intelligently, to speak persuasively, and to acquire a fundamental level of competence in math and science.

—*Albert Gore, Jr. Speech–University of New Mexico, 1992.*

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Technology increasingly will affect teaching and research across the disciplines, while interesting questions at the margins of the disciplines will strain the traditional organization of departments. How will science be taught in colleges and universities as technology takes hold and the public becomes increasingly concerned about the costs of research and education?

It is folly to presume to predict the nature of the extraordinary developments in technology that will shape life in the 21st century. But surely rich and easily accessible databases, interactive computational experiments, virtual reality and nth generation computation will affect all that we now do in the classroom and the laboratory. Assuming that the college as we now know it—a place away from home where students and faculty come together to learn and understand—does not disappear, our current reliance on the lecture as a technique of instruction will not speak either to our needs or our constraints: databases of easily accessible lectures by leaders in every field, computer interactivity across the world, and the need to individualize instruction in an economically constrained environment will all militate against gathering students to hear a professor lecture, no matter how brilliant.

Independence and discovery will become more central to the educational process, creating an environment more like that of 19th century Oxford, than the Sorbonne of today. Laboratories will have to be constructed to withstand the hard use of young people exploring on their own, with minimal supervision, and the faculty will be engaged in tutorial-like instruction, emphasizing the individual needs of students. Some experiments will exploit virtual reality—no noxious chemicals there—while others will be computer interactive with enough artificial intelligence to take account of student idiosyncrasies.

With so many interesting questions arising at the interstices of disciplines, and knowledge increasingly interrelated, departments as we know them will cease to exist: ad hoc groups will come together and disperse as common interests develop and wane. Students will study science in settings resembling the New Pathways program at Harvard Medical School rather than in, say, a physics program of today; that is, scientific problems will themselves generate the explorations of what are now the disciplinary ideas "owned" by departments.

With substantially more flexibility in the way knowledge is organized and presented, nonscience students will be able to pursue their studies in exactly the way future scientists do, but not necessarily at the same level of sophistication. Indeed, with growing concerns about public policy issues in medicine, technology and law, among other areas of concern, the well-educated citizen will not wish to leave science to the professionals. Everyone needs to understand how scientific knowledge is organized, and questions or disagreements resolved.

As we look ahead, there is a danger that science within the academy may be so starved for resources that separate institutions are formed, on the model of NIH, with only a passing connection to the academy. Perhaps the college/university will not be able to accommodate more than tabletop science. While this shift might seem economically attractive in the short run, especially as the public becomes ever more restive about the cost of higher education, it would lead to a weakening of the high level of training for undergraduate students. The academy must continue to engage the world of politics, even if only as "public intellectuals," in the interest of education and knowledge.

Finally, how might we best prepare for the future? Create a community of scholars, develop a lean, lab-rich curriculum, and enrich opportunities for independent exploration of our physical reality. We can no longer organize the teaching of science around answers to questions that students have not asked.

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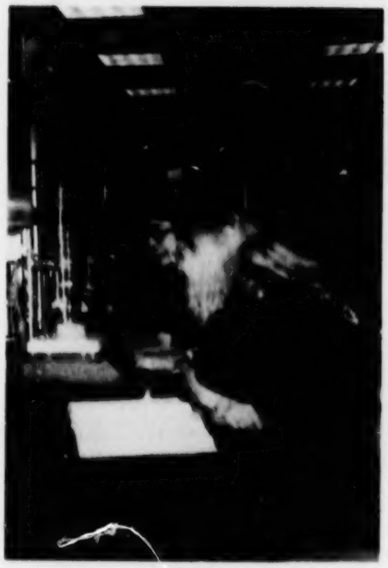

I cannot predict future needs any better than can anyone else. But one can look back 35-40 years to see how people thought then, to see how many were able to foresee with any accuracy what today's circumstances and objectives would be like. The impact of computers—especially of international computer networks—was virtually invisible. Just 10 years ago it was still an uphill battle to get college faculties to think of computers as more like telephones than as adding machines or typewriters. Who would have predicted the arrival of national standards for school education, and the discussion of national standards for higher education? How many would have predicted that the average age of college students would rise to nearly 30—as it is now—or that 80 percent of students in undergraduate mathematics would be studying subjects commonly taught in high school?

Today's curriculum, even if revised just last year, is not a proper base for designing a permanent facility. The design goal of the facility needs to be flexibility, to permit easy and inexpensive conversions to uses not yet conceived. The questions should not be so much about ideal circumstances for the best of today's pedagogy, but about facilities that could serve a variety of styles, subjects, and approaches to education.

The impact of international computer communications will radically change the very concept of a college or university. Resources for learning—traditionally professors, libraries, laboratories and texts—will soon become a "virtual university" available to any student anywhere. This will happen sooner in sciences and mathematics than in other fields, but it is coming everywhere. Science revolutions now come too rapidly to be held back by mere bricks and mortar.

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The amount of information becoming available in the sciences is increasing at an astounding rate. In the field of genetics, for example, it has been estimated that the amount of new information doubles every 4.5 years! That means that in barely more than the normal period of time for a student to achieve a college education, twice as much knowledge in this one field of study will be available for learning. Does this mean that faculty should lecture faster? Does it mean that historical information is of little value relative to what is new? Does it mean that genetics should become a sequence of courses rather than the traditional one or two courses?

In my estimation, the above example suggests that science education in the future, by necessity, will focus on helping students to understand better the nuances of the scientific process, to gain perspective on making judgements on scientific issues relative to what issues are pertinent to any given situation, and to learn how to use data and information acquisition systems effectively to gain access to pertinent details about a particular subject.

Students who specialize in science will continue to do so and they will most certainly seek in-depth answers to issues of personal interest, but no longer are students identifying themselves as a major in biology, chemistry, etc. Science is, always has been, and will forever be an interdisciplinary course of study. The interdisciplinary nature of science will be recognized in a formal manner, and by 2025 first-year students at universities and colleges will take some one (or set of) common denominator courses that will introduce them into the art of scientific investigation.

Many issues heretofore not traditionally associated with the sciences will become integral to all courses taught in science programs. Communication of scientific issues, principles, and thoughts will be a must, and thus students will be helped to develop skills in writing and public speaking. They will also be encouraged to question critically what they read (in both technical and popular literature) and to ask informed questions about relevant issues. Ethics in science will become of paramount importance (it already is important but not necessarily stressed) and students will be challenged with important tasks involving "risk assessment." For example, questions pertaining to issues about whether a scientific fact should be sought (e.g., splitting the atom) will be weighed against how this fact could be used (e.g., bombs or power).

Mathematics will increasingly become the language of the sciences. Mathematicians will finally come to grips with the understanding that "applied" mathematics is not bad, and we will find many mathematically-oriented scientists dispersed throughout what will be a large, interdisciplinary scientific division within an institution.

Finally, science will once again assume its overall importance in the general education of all students. Majors and nonmajor course distinctions will no longer exist, and issues of science will be dealt with in all fields of study throughout an institution.

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As we approach the year 2000, our world grows more exciting and more complex. Consider the increasingly sophisticated nature of work and relaxation; the growing interdependence of diverse cultures; the pervasive communications media that influence the way we think and act; the ascendance of disciplined, hard-working actions; the growing aspirations of less developed nations; and the concern for environmental fragility.

Complexity requires specialization in the pursuit of discovery as we deepen our understanding of the modern world and create the knowledge needed to resolve current dilemmas and improve the quality of life. In this process, we continually fractionate knowledge, analyzing the pieces in greater and greater depth. We have trained our 20th century professionals quite well in this task—it is a global strength we must sustain—but what additional skill will be demanded of 21st century leaders?

Within [academic] communities, in particular, we must create an intellectual environment where students can develop an awareness of the impact of emerging technologies, an appreciation of engineering as an integral process of societal changes, and an acceptance of responsibility for civilization's progress. Our intellectual mission must include the cultivation of each student's ability to bridge the boundaries between disciplines and make the connections that produce deeper instincts. To pursue this destiny, we need to create a working environment conducive to increased teamwork as well as individual recognition, and to reward excellence derived therefrom.

—Joseph Bordogna, Engineering Education: Innovation on Integration Engineering, 1993.

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Thirty years from now what will it be like? The barriers that currently exist between science, social sciences, humanities, and the arts will have been removed. Faculties in the humanities will teach the history of science, logic in science, and scientific writing as they do American history, Greek logic, or creative writing. Science faculties will incorporate in their classes the social implications of scientific discovery, art forms in science, and other topics that currently appear at the fringes of classroom instruction. This unification of faculties, made possible by increased international competition in technology which led to a rapid increase in the science literacy in the early years of the 21st century, has resulted in an increased humanization of science. With greater public understanding of science, decisions in science and technology were made by a broader spectrum of citizens.

The typical curriculum at colleges and universities devotes two years to introductory courses that include language, writing, social history, science, art, and mathematics. Each student is expected to take unified courses in these areas which are taught by college/university master teachers. All of the courses have a laboratory component which exposes students to the practice of the discipline. Science courses provide broad exposure to the traditional areas of biology, chemistry, earth sciences, physics, and technological science. The remaining two years of the four-year curriculum are devoted to specialization in a field of student selection, based on performance and available positions. Because colleges and universities now include a cap on admission to specializations, consistent with national employment needs, not all students are admitted to their first choice of specialization. However, graduates are now guaranteed placement in schools for advanced study, industry, or government as a result of the active role that society has taken with education.

Specialization is related to the European system of education developed in the 20th century. Research is an expectation of all students, although original research is normally performed by those students who are expected to enter schools for advanced study. However, faculty are expected to be continually engaged in research to guarantee their ability to prepare the next generation of scholars and to advance their discipline. Universities employ teaching specialists and faculty. The teaching specialists prepare the framework for instruction (technical displays, laboratories, demonstrations); the faculty implement instruction and engage students in original investigations. Thirty years from now there are twice the number of teaching specialists as there are faculty, but the number of faculty is only about one-third their number at the end of the 20th century.

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In 2025, an undergraduate with a pocket computer notebook will be able to choose from among different types of educational experiences. There will still be liberal arts colleges that are residential in character and personal in approach; however, they will function without science departments since the sciences and mathematics have become so interconnected that departments no longer make sense. On the other hand, there will be no more research universities that provide on-campus instruction; they will have evolved into research institutes that provide only on-line lectures that registered students receive at home. There will be graduate students at the institutes who serve as TA's for the courses. They will meet with students in an on-line discussion, similar to chat rooms offered by home computer services. Some existing facilities of research universities will have been sold to a new type of institution, the "university learning center," which will be an entrepreneurial center connected to a national network.

Students (in science or in the arts) will go to the center for an extended residency at regular periods, for hands-on activities within a laboratory, so that the experiential aspect of learning can develop over time. Since many science classes at universities will not offer laboratory work, the experience of the practice in these fields will be carried out by students downloading data and providing analysis and design of future experiments based on that data.

Liberal arts colleges and comprehensive universities are likely to take advantage of the on-line lectures from the research institutes in several ways. For example, students may be able to take courses, including elementary and intermediate languages, and complete a degree in two to four years. The language facility of science students would be valuable for potential international internships. On-line instructors would be available 24 hours a day. It is also possible that secondary school science and mathematics courses could be taken by high school students, thereby giving them additional credit hours upon entering college.

In 2025, no distinction will be made in teaching at the undergraduate level for majors and for those who are not majoring in the fields of science and mathematics; it will be obvious that all citizens need to be comfortable with science and technology. By 2025, we will have determined how best to incorporate an ethical dimension into learning science and technology, we will know how to assess the value of active learning, we will have determined the right balance between "content" and "process" in our teaching.

Facilities will have interdisciplinary labs not connected with a particular department; facilities that can be used for truly interdisciplinary teaching and research. Moreover, these facilities will promote interdisciplinary interactions, by having faculty offices and research labs arranged in close proximity according to interdisciplinary areas of research (for example, biotechnology, materials science, surface science, etc.) rather than having a separate area or floor for each department.

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Although much is sure to happen that we cannot anticipate, we foresee two major trends as having powerful impacts on what society will demand from universities and colleges. One is ever more rapid technical change. The stunning developments over the last decades in areas from microcomputers to biological engineering are only beginning to reveal their consequences. Many of these developments not only have generated and will continue to generate significant technical changes—they also provide a powerful engine for the further acquisition of new knowledge. Second is the increasing internationalization, even globalization, of the U.S. economy and society. Abetted by rapid advance in communication technology, it is clear that future citizens will need to be comfortable with a much broader range of languages and cultures than they have traditionally required to live their daily lives. Higher education will play a central role in preparing citizens for this world.

—Michael S. Macpherson and Morton Owen Shapiro, Spelman/FIPSE Conference on The Future of Higher Education, 1995.

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Although I am at a loss to envision science education in 2025, I predict changes in undergraduate science education in the next thirty years will continue to increase at an accelerating rate. These changes will probably be considerably more dramatic and unpredictable than those in the past thirty years. If current trends continue, we'll need curricula and facilities that support collaborative learning, informal student-teacher interchange, the study of interdisciplinary topics, and the use of sophisticated computer tools and scientific instruments.

In the face of accelerating change it will be critical for teachers to realize that what students learn will be less important than how they learn. Recently a physicist, just retired after a long career at Los Alamos National Laboratory, listed about 20 topics: laser spectroscopy, telemetry, neutron activation analysis, nuclear magnetic resonance, electron spin resonance, tunneling phenomena, electron microscopy, etc. Students were mystified when asked what these topics had in common: none of these topics were in the curriculum when he graduated from college in 1949 and he had worked on *all* of them during his career. Alas, very few of these topics are in the undergraduate physics curriculum today!

In the face of uncertainty about future areas of scientific research and the nature of research tools it will be critical to make new facilities as flexible as possible. Between now and 2025 instructors and students will probably use facilities in ways which are currently inconceivable. Suppose the disciplines are disbanded? Can laboratories and classrooms be reoutfitted to support interdisciplinary work? Is conduit installed so electrical and computer networks can be repositioned whenever the furniture is completely rearranged? Is the furniture modular and sturdy? Are there spaces for large, medium, and small groups to work collaboratively? Are there spaces where individuals can pull away to ponder and reflect? What about ceiling and floor hooks? What about access to computer media? Internet? Telephones? The outdoors? The metaphor for the science laboratory-classroom of the future is that of a giant electrical Lego set capable of being constructed in an endless array of fractal patterns to enhance learning through both collaboration and individual discovery.

Over thirty years ago John Steinbeck observed:

"We…can have no conception of human life and human thought in one hundred or fifty years. Perhaps my greatest wisdom is the knowledge that I do not know. The sad ones are those who waste their energy trying to hold it [change] back, for they can only feel bitterness in loss and no joy in gain."

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WHAT WORKS

The Student's Perspective

We began this Handbook with the questions: *"How can we improve the environment for learning? How do we know what works?"* We end by answering those questions with comments from students involved with PKAL Programs that Work. These comments, and the experiences of countless other students in colleges and universities across the country, demonstrate clearly that when students become part of a natural science community during their undergraduate years, they gain "...part of the intellectual equipment of an educated person...," delighted and surprised about the process of exploring and discovering their world.

Students say:

◆ Perhaps one of the greatest accomplishments was that we learned to ask questions and to solve problems. The result is that we were able to make decisions at all stages of the research...from beginning to end, which is a rare occurrence at the undergraduate level.

◆ It's been fascinating to see a 'real lab' in action; this research project has had an incredible impact on my interest in science, because it put science in a new perspective. I was given the opportunity to see science in action instead of just in a textbook. This has definitely been an incentive to continue in science.

◆ High school had convinced me I was not a 'science person' and I didn't realize before taking this class how much I underestimated myself in math and science. I am surprised by knowing that I worked with the EMG and with computers with full understanding of how they function. The statistical analysis alone made the whole process worthwhile, but the idea that I am now capable of comprehending primary scientific articles is amazing to me. I find myself chatting about science with friends for fun.

◆ I cannot express sufficiently the impact you have made on my confidence, drive, and overall outlook on life. Whether it was helping me to approach problems logically, to prepare applications for scholarships and medical school, your kind efforts will not only be remembered, but also practiced by me as well. (Although I can never honestly say I enjoy chemistry, I don't hate it nearly as much.)

◆ The new approach in this class is excellent. All the material we covered was used continuously, therefore it was material that I learned. Instead of worrying about a midterm or final, I was more concerned with absorbing the material on a long-term basis. This course aimed at understanding concepts, rather than memorization, and using the instrumentation gave me an idea of what modern chemists actually do.

◆ This type of original research turns people on to the sciences. Even as an undergraduate, you can think you are contributing to the scientific community. Gaining that sense of community and collegiality with other scientists gave me a sense of identity. I have begun to feel like a scientist.

The undergraduate years are critical for strengthening our nation's science and mathematics capacity. It is in college where future scientists and college faculty are recruited and prepared for graduate study; where our nation's elementary and secondary teachers, educators of America's youth, are equipped; and where tomorrow's leaders gain the background with which to make critical decisions in a world permeated by vital issues of science and technology. It is also at the undergraduate level where many able young people—particularly minorities and women—decide to discontinue their study of science and mathematics. The result is a serious loss of talent to the service of the nation, a loss that we cannot afford if we are to remain competitive in a global economy.

Unless everyone with a stake in undergraduate science and mathematics education makes tough decisions now about strategic priorities—about dollars, people, space, and time—effective reform will not happen. Effective reforms take money, to be sure. But more important is an environment for reform that encourages planning, fosters creativity, and rewards useful innovation. The environment for reform must be based on a driving vision of what works.

—PKAL Volume I.

Conclusion. For Project Kaleidoscope, our focus on building structures for undergraduate science communities is also a *work in progress*. We intend to continue to explore and discover how good spaces facilitate strong undergraduate programs, ones in which the attention of students is caught, *driven by curiosity, delighted and surprised to learn that science is.…an "endless frontier."*

The very work of developing this Handbook has been one of explorations and discovery for us in PKAL. Reflecting on the words of T.M. Greene with which the Handbook begins, we have been challenged again and again to think about the organic nature of the process. We have come to realize that the various descriptors of work of art as a biological organism, composed of parts that contribute both to the life of the whole, dependent one upon the other for their own being, seemed for us to ring true on so many levels—including the caution from a lab designer that each part to the HVAC system needed to be chosen both for its individual qualities and for how it fits into the larger system.

But most important, the challenge to think about the larger whole gave us a new way to look at the many stories and case studies presented throughout this Handbook. Our nation's undergraduate sector is not homogeneous, but perhaps for the first time in many years there is a growing consensus about what works to attract and sustain student interest in the fields of science and mathematics. The individual stories and case studies are evidence that institutions of all sizes, with different histories and goals, are giving serious attention to the question to the question, *"How can we improve the environment for learning?"*

The answers to this question, expressed in new facilities for science on campuses across the country, are remarkably consistent, suggesting a new life and vitality for the undergraduate community. Do we have a collective vision of our mission? Can we continue building a national natural science community? We must, as we go carefully into the future.

PKAL will continue the conversations about building natural science communities, in workshops and through the PKAL Internet. We will continue to seek examples of structures and spaces that work, fully aware that there are many more existing examples of facilities that work than we could capture in these pages. As they are brought to our attention, they will be included in future PKAL publications and workshops. We also want to learn how new ways of looking at how students learn and how changes in the disciplines and in technology change the way we shape our spaces into the future. We look with great anticipation for reports on facilities projects that are completed in coming years—spaced and structures that will accommodate natural science communities, even to the Year 2025.

APPENDICES & EXHIBITS

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